Opportunities for Ubiquitous Design Environments in a Flat World

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Abstract:

A ubiquitous design environment is a research platform designed for support of virtual, distributed and physical design processes. These environments are contributing to design engineering research and education. A flat world not only increases the need for coordination, collaboration, and efficient transfer between physical and virtual design but also the importance of creative processes and innovative solutions to diverse problems. Ubiquitous design environments integrate existing systems such as design observatories, computer supported collaborative work environments, and bench top fabrication facilities, and have the potential to address many of the challenges and leverage many of the opportunities of a flat world (Friedman 2005). Incorporating affective agent research platforms – real-time multi-modal affective sensing and feedback mechanisms – into ubiquitous design environment can provide participants with dynamic interactions to facilitate understanding of and engagement in diverse stages of the design processes. These environments can provide interventions and interactions ranging from the display of simple interface elements, such as a bar graph of participants' level of involvement, to supportive virtual characters serving as affective learning companions or design partners, clients, or mentors. These interactions and virtual participants are equipped with embedded models informed by design research and social interaction theory. They are used to provide support for reflective practice, brainstorming, metacognition, meta-affective skill, and elements of the creative process for individuals and teams. Ubiquitous design environments are being developed and used in multi-campus engineering education, public workshops, and sustainable product design collaborations that focus on entrepreneurship and global development.

1. Introduction

In the context of a flat world, in which teams of engineers and clients interact and design in a distributed manner, design processes that are already challenging become even more complex. Issues of coordination, collaboration, and efficient transfer of information and material between physical and virtual domains arise. More importantly elements of the creative processes are challenged; these elements must be sufficiently understood and supported to facilitate innovative solutions to diverse problems. "Ubiquitous Design" is a research agenda that is focused on developing a variety of advanced design environments that leverage ubiquitous and distributed computing systems through novel applications that facilitate design research, education, and practice. Ubiquitous Design Environments have three primary functions: first, through sensors (video and audio, physiological, contextual, behavioral, wearable, etc.) they provide researchers, designers, and the systems "themselves" the opportunity to observe and archive design activity and processes; second, these systems can readily provide new tools to designers, making a variety of design tools and practices more accessible in a distributed and ubiquitous manner; and third, these systems have the ability to employ embedded theories of design and collaboration to provide interactions and interventions that enhance designers' process, skills, creativity, and innovation.

The development, implementation, and study of these environments incorporate theoretical frameworks from several disciplines that directly relate to design and design research. These integrated frameworks and systems are providing opportunities to study design activity and affective experience through several novel interdisciplinary methods. These advanced systems are increasingly able to actively participate and collaborate in design processes with their users through interactive relationships with multiple participants. This agenda employs new technologies, such as real-time affective sensing to measure and interpret elements of user experience such as physiology, contextual actions, and social interaction. The application of these systems is being explored through multi-campus collaborations in engineering education, sustainable international product design and development efforts, and through empirical studies that focus on brainstorming and creative processes in distributed environments and trans-disciplinary teams.

Ultimately this research is contributing to the construction of a deep understanding and improvement of design process, the role of affect and social interaction, and the relationship of the physical and virtual within co-located and distributed team processes.

2. Background

Advancing Ubiquitous Design requires the identification and application of relevant theory, collaborative system development and integration efforts, and evaluation that is supported by multiple methodologies (Burleson, 2005; McGrath 1995). This section will discuss the emerging theory, systems and fabrication tools that are being applied to the development of Ubiquitous Design Environments.

Theory:

Real world projects motivate engineers and designers through direct connections and involvement of the end-users in the design process. Von Hippel provides important strategies to facilitate this inclusive practice through his work on "lead users" and on "democratizing innovation" (von Himple 2005). As a broader population across a flat world adopts Von Himppel's approach, non-expert designers will need support in their processes. Design research and education are important sources of theory that provide supportive strategies; they also provide valuable means for evaluation. Schön and more recently Adams et. al. have emphasized the importance of reflection in design engineering practice and have highlighted opportunities to "educate the reflective practitioner" (Schön 1987; Adams et al, 2003). While fostering reflection is an ongoing challenge to design processes, a flat world increases the asymmetry and diversity of engineering teams. To better understand asymmetry and diversity within teams engaged in design processes, the fields of social, behavioral, and organizational psychology provide valuable perspectives and methods. These fields study the practices of effective teams and leadership (Hackman, 1998); practices and efficacy of distributed work and teams, e.g. Knowledge Distribution Initiative (Cummings and Kiesler, 2005; Hinds and McGrath 2006); and provide theories and findings from the study of creativity. Amabile has developed a componential model of creativity (Amabile 1983) and shown the strong connection of affect to creativity at work (Amabile et. al. 2005). Isen's has demonstrated the influence of affect on creativity and positive social interactions (Isen, 2004). Csikszentmihaly has articulated a systems model of creativity and elucidated the structure of *Flow,* optimal experiences, and their importance to creativity (Csikszentmihalyi, 1996).

Recent findings on affect from organizational behavior, business, and creativity research indicate that affect and an individual's perspective plays a highly significant role in a wide variety of cognitive and social processes for individuals and within teams. In the engineering process, failure, repeated failure, and learning and recovery are essential. However, failure and setbacks can lead to negative emotions, which tend to persist significantly longer than positive ones, a phenomenon known as negative asymmetry (Ref). People, when they experience sadness, elect to purchase products at higher prices and sell products at lower prices; sadness also leads to less success in negotiations (Lerner 2004). Applications addressing negotiation in design contexts and contracts could take this into account. While some mild negative emotions improve performance on certain algorithmic analytical tasks, the study of positive affect indicates that positive emotions promote generosity and social responsibility; increase self-efficacy and motivation toward accomplishment; and facilitate openness, flexible manipulation of new information, and creative thinking (Isen 2004). The importance of the link between affect and creativity is extended to teams in Elfenbein's research, which has shown (Elfenbein 2006) that affect and first impressions within teams predicts productivity outcomes. Thus, the composition and perspective of teams and team members plays an important role. Atman has found that gender differences also contribute significantly to this diversity of perspectives, e.g. girls in her studies emphasize the importance of social interactions and understanding the problem while engaged in the design process while boys emphasize modeling and building (Atman 2007).

Systems:

An interdisciplinary community of researchers and practitioners has developed through events such as the 2002 CHI Workshop on Creativity and Interface, the 2005 NSF Workshop on Creativity Support Tools; the

Computer Supported Collaborative Work, and the Creativity and Cognition Conferences 2003, 2005, and 2007. This community is developing tools to support creativity; some of their systems incorporate elements of the theories of creativity, distributed work and design practices discussed above. The iLoft and Design Observatories research at Stanford University seek to capture and analyze design activity through smart walls, tablets, and synchronized multi-source video and audio capture (Carrizosa et al, 2002; Eris, 2004; Milne, A.; Winograd, 2003). The iLoft provides tools to enhance designer's processes and support them with capture, sharing, and manipulation of design process artifacts (sketches, notes, audio, pictures, etc…). Using more traditional observational techniques, Atman has a body of research that has coded individual's patterns of behaviors in design processes and Yasar and Henderson have extended Atman's coding scheme for the observation of teams (Atman 2003; Yasar and Henderson 2007). Observational systems, such as design observatories, facilitate the capture and coding of patterns of design activity and more recently elements of designer's affect (Eris 2004; Ade Mabogunje 2006). Discussed in greater detail below, affective computing strategies and affective agent research platforms provide a complementary approach to understand the activity and behavior of designer's physiological and contextual states (Picard et al. 2001).

Recently developed systems and research on groups presents significant opportunities for the study and support of design processes through sensing, feedback, and interactivity. Smart Badges that monitor verbal social interactions can determine dominant structures in groups and other parameters of conversational behavior (Pentland 2005). DiMicco showed that providing a bar graph presenting the cumulative vocal involvement of each individual group member served to increase the participation of under-participating members. This increased the under-participating member's disclosure of salient information to the group and thus improved the quality of discussion, decisions, and outcomes (DiMicco 2006). Virtual characters, acting as peers, mentors, coaches, and facilitators, can provide another form of feedback, intervention, and interaction; this is a strategy that is increasingly used in intelligent tutoring systems (Bickmore and Mauer 2006). Future systems may include real-time Brain Computer Interfaces (BCI) that use functional Magnetic Resonance Imaging (fMRI) or other techniques to detect moments of insight - Eureaka Moments (Kounios et al. 2006) – and respond appropriately to them. In the meantime affective sensing may enable virtual and distributed participants to be aware of and share in the excitement of a team member's discovery.

***Fabrication**:*

While the above systems detect, influence, and interact with social structure there are also important developments that contribute to designers' abilities to physically express and test their designs. Low cost and networked rapid prototyping and fabrication tools are emerging. One particularly exciting effort is this area is Gershenfeld's Fab Lab (Gershenfeld 2003, Gershenfeld 2005) which is placing sophisticated design tools in the hands of distributed communities and end-users. These systems are empowering users to design their own solutions to their local design challenges and enabling them to share these with other communities, and learn from them as well. The community of Fab Labs and users is distributed to over twenty sites and six nations. Understanding how to support constructionist activities in these distributed design environments has profound implications for grass-roots community development (Baktiar et. al. 2002) and presents an important opportunity for design research.

3. Ubiquitous Design

Ubiquitous Design Environments integrate theory, systems, and fabrication to achieve three primary functions: first, they advance theory by sensing, capturing, observing, and providing the raw data for understanding the design process; second, they assist designers and users by providing new tools for collaborative, distributed, and advanced rapid prototyping, such as those provided by the iLoft, CSCW systems, and the Fab Lab; third, they facilitate the design process through interactions that apply embedded theories of design and collaboration to enhance designers' process, skills, creativity, and innovation.

To advance the Ubiquitous Design Environments research agenda requires a team of individuals that can provide the strong interdisciplinary skills that are necessary. The work is grounded in cognitive and social theory, an understanding of the physiology and psychology of affect and learning, and the philosophy of context. It demands an ability to relate these to the development of refined functioning systems that support interactions and relationships. Design and mechanical and materials expertise are needed to invent, engineer and craft elegant prototypes, research platforms and environments with embedded electronic sensors and actuators, develop algorithms for multiple data streams, and integrate numerous computational architectures. The process is guided by iterative evaluation using diverse methodologies: field studies and ethnography, respondent techniques, participatory design processes, heuristics, expert review, and experimental studies. The research focuses on the intersection of people, experience, technology and design, to understand affective experience and learning and enhance individual and team creative processes.

Affective Design Companions:
In the Affective Computing Group at the MIT Media Lab and as part of the Lab's Things That Think Consortium, a community that focuses on inventing the future of digitally augmented objects and environments through science, engineering, design, and art, I developed the first "Affective Learning Companion System." At Arizona State University I am now transforming the Learning Companions into Affective Design Companions. Affective learning companions are relational agents that sense elements of human emotion, excitement and frustration, and display emotions as a means of fostering learners' affective self-awareness and metacognitive strategies. For example, an Affective Learning Companion sensing user interest through patterns of posture, pressure exerted on the mouse, and skin conductivity might choose to delay intervention to allow the user to continue exploration. On the other hand, if frustration were sensed, the companion might display concern through appearance and body posture as it engages in non-verbal expression as a form of empathy. This interaction could provide elements of peer social support and draw attention to the user's affect in order to facilitate self-awareness and mitigate some of the negative impact of frustration.

The affective agent research platform that supported the affective learning companion integrates an array of affective sensors in a modular architecture that drives a System Server and Data Logger, Inference Engine, Behavior Engine, and Character Engine. The Character Engine includes dynamically scripted character attributes at multiple levels. This approach is particularly suited to affective expression. The user sits in front of a wide screen plasma display. On the display appears an agent and 3D environment. The user can interact with the agent and can attend to and manipulate objects and tasks in the environment. The chair that the user sits in is instrumented with a high-density pressure sensor array and the mouse detects applied pressure throughout its usage. The user also wears a wireless skin conductance sensor on a wristband with two adhesive electrode patches on their hand and forearm. Two cameras are in the system, a video camera for offline coding and the blue-eyes camera to record elements of facial expressions. This multi-modal approach to recognizing affect uses more than one channel (e.g. facial expression alone) to sense a broad spectrum of information. This approach applies techniques from psychophysiology, emotion communication, signal processing, pattern recognition, and machine learning, to make an inference from this data. Since any given sensor will have various problems with noise and reliability, and will contain only limited information about affect, the use of multiple sensors should also improve robustness and accuracy of inference.

In this way I am developing technologies that provide social structures through interactions and relationships between people, products, environments, and experiences that are enhanced because they actively take into account and respond to users' emotions and contexts. Through a series of studies with over 100 users, evaluation of this system demonstrated the importance of appropriately attending to users' affective states while helping users' persevere through a frustrating problem solving activity (Burleson 2006).

The initial development of a ubiquitous design environment is extending the architecture of the affective agent research platform and applying it to the broader context of supporting design processes and facilitating team interactions. Just as intelligent agents and smart objects that use models of human behavior, affective sensing, and context awareness to guide their interactions are beginning to have the ability to sense and express affective states, they may also have the potential to improve human creativity. Investigations in the workplace suggest that, in addition to affect, high time pressure impacts creativity, but not in the way that people believe it does. While most individuals think they are more creative under high time pressure, this circumstance actually decreases people's creativity by 45%. Heightened creativity is only achieved in five percent of high time pressure instances when individuals believe they are on an important and urgent mission (this is frequently the experience in which design teams find themselves). Likewise, understanding how to deal with frustration, failure, and how to persevere are central to problem solving and design activities. A credo from Stanford University's Design Division states that, "A spectacular failure is better than a moderate success," a second one states, "To succeed in the end you must, fail early and often." In the process of developing the affective learning companions the theory of "Stuck: a State of Non-Optimal Experience" was developed to better understand the opportunities for an affective agent research platform's support of frustration (Burleson and Picard, 2004). Stuck directly parallels Csikszentmihalyi theory of "Flow: Optimal Experience" (Csikszentmihalyi 1990). These theories are now being applied to the evaluation of the ubiquitous design environment.

Several fundamental questions are being investigated as these findings and theories contribute to the understanding and advancement of design and design engineering research processes. How do individuals develop emotional relationships and experience with agents, objects and their environments? How can designers create technologies to enhance relationships between people, objects, and environments that bring new and more profound meaning to the interactions?

Through a process of design and evaluation, interdisciplinary research methods from the fields of human-computer interaction, social psychology, and design research, are extending the affective agent research platform to support the Affective Design Companions and their interactions within a ubiquitous design environment. In conjunction with the affective design companion, the observational cameras and microphones of a design observatory are being deployed along with an MIT Fab Lab style rapid prototyping facility. System support for capture, playback, annotation, and collaboration is also being developed. Additional interventions and sensing abilities are being developed for use with MIT's smart badges and group feedback techniques.

Digital Sketching Pens:

One particularly lightweight system that is being developed is a digital sketching pen. Take, for example, a pen augmented to detect the pressure applied to its surface and the research on affect, productivity, and creative processes that this pen could facilitate. The system clock would enable the pen to track duration, interval, and time of day. The pen could begin to characterize its usage, detecting when the user is jotting a quick note, writing prose, or drawing; it could possibly also detect elements such as line quality and user skill. A study at Harvard and MIT showed that the application of mouse pressure was correlated with the perceived frustration of a user interface; a similar study with a pen might also be expected to uncover affect-sensitive patterns (Dennerlein et al 2003) These patterns could then be used to develop a real-time embedded model of stress. With this awareness and an ability to interact through an LED, this pen could potentially direct attention to stress level, acknowledge changes in pressure over time, and promote change of usage from writing to drawing, drawing to annotation, and suggest or facilitate taking a break. When should it intervene, what are the impacts for learning and creativity, and how would the user feel about these interactions? Pens for design and engineering students, who are learning to think and communicate fluently and flexibly through sketches and descriptions, could track writing and drawing and encourage a balance of both. Pressure data from the class could be used to investigate patterns of use and stress during brainstorming and over the course of design projects. Such a pen could elucidate several design research questions. How do pen designs affect pressure, stress, and desirability? What are the drawing, writing, social patterns, and stress dynamics of brainstorming sessions? Are these patterns synchronized across participants or correlated with time pressure? When is stress beneficial and when is it counterproductive? How can pens' interactions with one or more users facilitate affective relationships, promote skill development, productively alter stress level and time pressure, and foster brainstorming?

A pressure sensor on a pen can pick up information that often changes in predictable ways with feelings, even though it is not the same as sensing those feelings. While the pressure sensor alone is not able to distinguish between a squeeze and stress, with more context provided by built-in models of pressure dynamics and affect, this and other sensors can sometimes distinguish emotion states. This awareness of the emotional state can be designed to facilitate the user's objectives. A constellation of networked objects connected in wearable and ubiquitous sensing environments could strive to act synergistically on behalf of their users. Educational products and environments that can gather affective data and track interactions in natural environments in real-time offer the potential to create activity awareness, enhanced relationships, and responsive environments: they offer the potential to fundamentally transform user experience and the design process.

Advancing Ubiquitous Design Environments:
Through exploratory design and user testing of smart systems, embedded technologies, PDAs, collaborative environments, and installations, this research agenda is applying expertise in affective and context aware computing to develop a new framework for the support of design and for the design of interactive technologies. In particular, it is bringing real-time affective sensing into the loop. This is providing the ability to sense and interact through affect. It is also contributing to new understandings of design and experience. This ability and understanding enable dynamic tailoring of function and focus, to transform user and team experience and outcome.

In the same way the Affective Learning Companion is being developed for every student, this agenda is developing Affective Design Companions and tools such as digital sketching pens to provide ubiquitous embedded agents with an understanding of human behavior and relational strategies, and capabilities that in some cases make them more aware and understanding of their users than the users themselves. The form, expression and interaction of these agents will be richly varied, ranging from the pen's LED to the actions of on-screen Learning Companion characters. These investigations will advance important research questions. Can these products and environments scale from individual settings to collaborative spaces and public settings? Can they recognize opportunities for collaboration, mediate interruption, dilute procrastination, and promote self-desired behaviors? These agents can be used to inform product design and design education to enhance designers' abilities and design research. Ultimately this agenda has ramifications for business, education, technology, and behavioral sciences to help individuals, social groups, and design teams understand, on multiple levels, their own needs, actions, activities, pursuits and outcomes.

4. Affective and Effective Teams and Flat World Research Activities:

Case Study:

Our first study is to describe the design process of three interdisciplinary undergraduate new product development teams comprised of senior students from four disciplines. We have identified teams in the InnovationSpace program for this study. InnovationSpace is a transdisciplinary product development program that gives senior undergraduates in business, design, and engineering the chance to work in teams of four on new product development projects in cooperation with outside sponsors. The InnovationSpace program is one of a handful of programs in the United States that offers a year-long interdisciplinary team product development course. We have recruited the students teams (3 teams with four members each totaling 12 participants) for two primary reasons: first, the teams have experience working together (this addresses the question of validity of studies with ad-hoc teams assembled solely for research purposes) and secondly because the teams are interdisciplinary (many studies of groups are disciplinary specific and ignore the real-world experience of working across disciplines and departments).

The three-hour protocols for each team are being coded using measures from previous studies. The products (task solutions) are being subjected to a consensual assessment (Amabile, 1996) by a panel of product development experts and students from the other participating teams. The MBTI types are being assessed to draw comparisons to previous work regarding team functionality based upon personality composition and the clustering of certain personality types within specific disciplines (Durling et al., 1996).

For the present study we are using a "design a playground task" that has been modified from a previous study in which it was used with individual participants (see Atman & Turns, 2001 and Atman et al., 2005). We gave the same design task to teams of senior undergraduate students currently working together in the InnovationSpace program (a transdisciplinary product development course that assembles teams of student from industrial design, visual communication design, business, and engineering for a senior year capstone project). Creativity researchers have recently recognized the need to use groups with some experience working together (Kurtzberg & Amabile, 2000-1) so we have specifically chosen to recruit teams that have been working together since the beginning of the fall 2006 semester.

The following two schemes, based on previous studies, will be used to code the protocol data: One includes eight steps (Problem Definition, Gathering Information, Generating Ideas, Modeling, Feasibility Analysis, Evaluation, Decision, Communication) and the second utilizes a different theory (focused on reflective practice), though also applied to the same 'playground' protocol data in the previous studies, and contains only four activities (Naming, Framing, Moving, Reflecting).

Process Measures from the protocol analysis include number of words spoken, time spent, number of transitions, transition rate, time spent in decision step, number of information requests, number of information categories covered. The original study that utilized this design task included task-specific information available to participants upon request during the process. Atman, who developed the previously mentioned study, has generously provided us with the exact information sheets used in the original study so as to improve the comparability of our results on this measure. Product Measures for the consensual assessment include solution quality, aesthetic appeal, technical feasibility, actionability, safety compliance, and creativity (as determined by the panel of expert judges and the other participants).

Initial Efforts and Global Opportunities:

As we move forward with the analysis of the data from our study it is well understood that the composition of teams and the responses of individuals create a rich diversity that presents added challenges to the study of in situ and distributed design engineering teams. Atman, for example, found significant gender differences in beliefs held by designers, as did the Affective Learning Companions study of learner's interactions with affective agents. When the learning companion provided girls affective support their meta-affective skill increased e.g. their ability to understand their own emotional states and to apply a productive learning strategy. Girls also experienced more Flow and reduced Stuck when affective support was provided vs. when task support was provided. Flow and meta-affective skill are two experiential elements that foster creativity and innovation. We are working with Yasar and Henderson at ASU to couple the affective sensing strategies with their group-coding scheme to study brainstorming, creativity, and innovation of pre-existing trans-disciplinary.

Linking our ubiquitous design environment to ASU's East Campus and to Leeds College of Technology in England will enable us to explore local and distributed collaboration in conjunction with Henderson' Global Resolve project-based curriculum (one of its current foci is to build low cost, individually operated water treatment facilities in Ghana). One of the first projects to use the Ubiquitous Design Environment is our development of a low cost infant incubator prototype with low-cost electronic thermal sensing, for Nepalese villagers. This work is being pursued in conjunction with the non-profit Design that Matters organization (www.designthatmatters.org). Future efforts in these globally distributed projects will be coordinated within and supported by the ubiquitous design environments. These environments are beginning to support and connect designers and to provide researchers the opportunity to further study design and team processes, outcomes, and creativity.

Conclusion:

As the world becomes flatter, as we work across countries and cultures in an asynchronous and distributed manner, the challenges of engineering are increasing. To understand these challenges researchers will require an increasingly transdisciplinary and multifaceted expertise. The ubiquitous design environment research agenda is drawing upon contributions, elements of theory, advanced systems, and physical fabrication capabilities, emerging from research across the fields of design engineering, psychology, business, organizational practice, etc. Integrating these contributions into a ubiquitous computing environment we are advancing an understanding of the design engineering process and an ability to influence and support that process to enhance creativity, productivity. Ultimately ubiquitous design environments are enriching the cultural exchanges that emerge in a flat world.

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