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THE iLOFT PROJECT: A TECHNOLOGICALLY ADVANCED COLLABORATIVE DESIGN WORKSPACE AS RESEARCH INSTRUMENT

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Abstract

For the past two years, the authors have been working to address the challenges of collecting data on design teams by creating a family of workspaces that design teams can utilize while researchers study their activity. A first iteration in this endeavor was the Design Observatory[1], which provided a space in which researchers could structured experiments with design teams. The latest of these spaces, the iLoft, is designed to attract designers to a suite of advanced collaboration and information technologies they can use in their regular work, and thereby provide greater opportunity to study their activity during design.

Keywords: collaborative design tools, distributed work, globalization

1 Background

1.1 Data Collection Challenges in Engineering Design Research

A design research protocol workshop held at Delft University[2] established that unstructured data sets can be interpreted in a wide variety of ways. Analytical approach is not the only variability in design research methods; data collection itself can take many forms, even though it generally falls in one of two categories: simulated experimental sessions and real engineering practice. While in the former case researchers can exert greater control and thereby manage the data collection process more effectively, the latter case presents more of a challenge.

Engineering design researchers today face a daunting set of hurdles in attempting to study design activity in realistic situations. Setting aside problems associated with negotiating access to team members, protecting intellectual property, gaining management approval and securing employee cooperation, researchers must develop suitable collection strategies that ensure that appropriate types and quantities of data are recorded. All this, while at the same time the data collection strategy must avoid interfering with ongoing engineering work.

Indirect data collection methods such as interviews, documentation analysis, and artifact dissection result in diluted data – i.e. data that is somewhat removed from the actual activity – and often lack the resolution that direct methods achieve. Direct methods, however, bring their own set of challenges. Methods such as participant observer reports and ethnographic observations are time-consuming enough that it is difficult to collect extensive data sets. Other direct methods, including video interaction analysis and verbal protocols, present the added challenge of adding time associated with analyzing the resulting unstructured data. Clearly improvements in data collection efficiency and access to data in real engineering situations could accelerate development of the design research field.

1.2 Information Technology as Instrumentation

Researchers at Stanford University's Center for Design Research (CDR) have, over the past decade, embraced a proven methodology[3] that follows an iterative process of:

- observing patterns of behavior
- analyzing causal relationships and opportunities for improvement
- intervening in the process with new techniques, technologies or systems appropriate to the phenomena under consideration

In the recent years intervention in the design process has often, but not always, taken the form of an information technology (IT) tool[4],[5]. It has become clear that interventions, i.e. the technology tools introduced in design processes, could be instrumented in such a way as to automatically collect data on design team activity that makes use of the tools. The concept of instrumenting design team activity is not new. [6] The notion that design is a hybrid socio-technical process means that communication and information exchange are at the center of all design activity. As such, tools that support these functions can "monitor" the essence of design activity. The idea of using IT tools as instruments when they are introduced to the design process is particularly useful since evidence shows that new technologies motivate users to co-adapt technology and workpractice simultaneously[7]. This means instrumented tools are placed at the point of greatest perturbation to the system.

An important condition on the success of this approach is that the tools must be considered sufficiently useful by the designers using them that they will in fact use them in their work, especially in the case where there are no redundant data collection instruments in place. This means that investigators must co-design the technological capabilities of a space and the nature of their research explorations.

1.3 Preliminary Work: the Design Observatory

An early attempt to address some of these issues took the form of the "Design Observatory" [1], a purpose-built research facility at Stanford. The Observatory embraces a doctrine of embedding instrumentation in an engineering design workspace. Instrumentation in this case consists primarily of video and audio recording capabilities that support video interaction analysis and verbal protocol analysis. The Observatory provides a number of advantages over past data collection practices:

- dedicated instrumentation setup reduces the amount of preparation required to run data collection sessions
- digital media acquisition and storage technologies allowed for more efficient data storage
- DVD recording systems and portable hard discs improve the portability of captured data
- experiments involving prototype technologies can be staged where support is close at hand

The Design Observatory, however, preserves some, and introduces other, disadvantages for design research data collection. The most significant of these are that the Observatory:

- removes engineering design teams from their "natural" setting
- continues to collect data in an unstructured, unfiltered format
- is limited in size, only comfortably supporting a single team of up to 6 individuals

The Observatory, then, is suitable for improving data collection methods under simulated, experimental conditions, but it does not improve the situation with regard to studying design team activity in real settings.

2 Interactive Workspace for Engineering Design

2.1 An Ecosystem Framework

In a previous paper, one of the authors[8] outlined a framework for design research that treated it from an ecological perspective. The paper discussed the fact that most research in design addresses issues of "population" (i.e. designers and design teams) or "activity patterns" (design processes & methodologies), occasionally examining "resources" (design tools) that support the patterns. Using this framework, the author pointed out that an under-examined aspect of the design innovation ecosystem is the environment.

A number of researchers have developed interactive workspaces [9],[10],[11] as demonstrations of how new media technologies might be applied to support team collaboration. For the most part, these projects have resulted in proof-of-concept workspaces, not robust or extensible enough for real users who can be studied under actual working conditions. In contrast, the authors and other researchers have recently deployed an interactive room infrastructure [12],[13],[14] in a number of spaces at Stanford University, including classrooms, research areas, and design project spaces. This infrastructure is both extensible enough to support interesting research explorations and robust enough to allow research-based tools (interventions) to be used in the context of ongoing design activity.

2.2 Workspaces for Engineering Design

Tang [15] and Minneman [3] were among early researchers to look beyond information handled in engineering design activity. Tang's work in particular sought to understand designers' activities and their use of workspace, with the intent of using this understanding to impact technology design. He determined that designers need to communicate more than just the information in their sketches and lists; they also use gesture with verbal exchanges to develop their designs. Minneman elaborated on the social aspects of design as a socio-technical process, in which design teams negotiate a shared understanding. Milne's[16] work furthered this line, quantifying the relative amount of information handing and team interaction that is encapsulated in design team verbal exchanges during a conceptual design activity. All of these studies take a broad view of design activity and design technology; activity and technology come together in the context of design workspaces.

2.3 A New Control Volume

In fluid mechanics, "control volumes" are applied to define an appropriate boundary of consideration when analyzing phenomena of interest; the selection of the volume – it's location and extent – determines what insight an analysis of the dynamic processes within it will provide. In the focus on team activity in engineering design, it is necessary to consider a broader control volume for information technology than that of personal devices.

To this end, the authors' work views interactive, team workspaces as an appropriate unit of study. This frame is appropriate since it:

- enables consideration of a "team-user," as opposed to a collection of individuals, for purposes of defining design requirements and architectural principles for new technologies
- provides a cohesive "unit" of activity context, one that can have simultaneous sub-activities and is realistic in IT usage in professional situations
- suggests the need for a better coupling between "traditional" IT formats and the physical aspects of the work environment, creating the opportunity to conceive new products
- is a meaningful conceptual frame that can be later applied to situations in industrial and research organizations that encourage collaboration in technical teams

2.4 iSpace Research

The iLoft project is one centerpiece of an international collaborative research effort seeking to understand how information technology needs to adapt in terms of its function, interfaces, and physical manifestation in workspaces to better support engineering design teams working in both co-located and distributed scenarios. Stanford's Computer Science Department has in the last three years been exploring new forms of collaboration technology, first through its iWork project, and more recently as a part of the iSpace research program. Organizationally, the iSpace program is a collaborative research partnership between Stanford University and The Royal Institute of Technology (KTH-Stockholm). Together researchers from both institutions have embarked on a two-year endeavor to develop new forms of human computer interfaces specifically suited to engineering design and to study the ways in which designers use these new tools. The project is organized into five modules:

- physical integration of technology into the work environment
- systems software infrastructure middleware
- information persistence
- post-desktop user interfaces
- design support

The first four of these modules focus on different aspects of technology development research. The final module provides context for the work, in that development efforts in all five modules have a shared stated aim of supporting the activities of engineering design teams. The partnership between computer scientists and design researchers is accelerating the pace by which experimental interventions can be devised, implemented, and studied in this context.

Early work in the iWork/iSpace projects centered on the iRoom, a meeting room located in the basement of Stanford's Computer Science building. As technologies developed, researchers in the department entered into partnership with others working at the Stanford CDR, and began looking at how the new technology capabilities would impact the performance of engineering design teams. The iSpace research team took engineering design teams as a focus, and began mining the existing knowledge base of design practice and methodology to develop new ideas for technology development. With the goal of getting closer to real engineering activities, it became clear there was a need for interactive workspaces that were open to engineers to use, but also had advanced technologies that would be the focus of studies. The iRoom was not suited to this purpose – it was too far from the locus of activity, presented an overly constrained environment that didn't allow for reconfiguration, and it was too much of a development testing groups. Similarly, the Design

Observatory was not suitable for this due to its size and the need to preserve its schedule flexibility for research experiments. The researchers needed a new place, preferably close at hand to ongoing engineering activity as well as to the researchers themselves.

3 The iLoft Concept

3.1 Technical Overview of What Makes an "iSpace"

The term "iSpace" has come to represent a category of interactive workspaces, each of which uses a common software system infrastructure called the Interactive Room Operating System, or iROS. At the heart of the iROS is the Event Heap, a server component that binds together networked devices in a workspace so that they can intercommunicate and present a coherent user interface for anyone in the space. iROS supports the PointRight system[17], which makes it possible for a single mouse and keyboard pair to control any of several computers connected to projected displays, switching between computers by merely moving the mouse off the edge of one onto another. Similarly, it enables MultiBrowse[18], an iSpace capability that allows users to easily "push" or "pull" web-based information between computing devices in a space. These are just the first, simple examples of the capabilities iROS enables. In a general sense, the system permits sophisticated applications in which inputs and outputs may originate from any one or group of devices, while computational processing could take place in still other devices. An example of this is WorkspaceNavigator [19], an application which provides information persistence in an iSpace by collecting synchronized information snapshots from whiteboards, computers, and webcameras in a space and making them available to users in a coherent form.

The iROS software infrastructure has allowed the rapid development, use, and observation of a number of relevant applications, many embodying key group-interaction technologies, including:

- Fluid interaction as a way of minimizing attention to tools [20]
- Moving information across shared displays and between shared and personal displays [18]
- Distributed pointer control over shared displays [17]
- Annotated spatial/electronic memory [19]

Because the Event Heap serves this central function, it presents a unique opportunity from an instrumentation point of view. By monitoring "event" messages passed through the Event Heap, researchers can collect data on any application-related activities occurring in the associated space. In support of this functionality, the current implementation of the Event Heap incorporates timestamps for all events and provides function calls that record all events – or a filtered subset – passing through the Event Heap. As a result, a text file of structured event data can be generated automatically anytime an iSpace is in use.

3.2 iLoft Design Issues

The prototype iSpace, the iRoom, was designed with three wall-mounted interactive rear projection screens, a projection display table top, multiple video cameras for remote viewing, a digital still image camera, and a high-resolution "information mural." The room systems were built from commercially available products with little physical modification. Over time, however, it became apparent that the prototype would need to be changed in certain ways if it was to meet the needs of engineering design teams and encourage them to use the technologies in the course of their regular design activities. Some of the primary design requirements that led to modifications to the original iRoom concept when applying it for the iLoft included:

- Increased flexibility and mobility – integration of physical and digital artifacts in a unified manner, physical mobility of large-scale interactive screens, ability to reconfigure the space easily to accommodate different activity modes.
- Scale – sufficient physical area to support both multiple small design groups and a single large presentation audience
- Ad hoc device connections – support for impromptu addition of new devices (e.g. notebook computers) to the infrastructure for short periods of time, and ability for those devices to interact with several different iSpaces through the course of a day
- Distributed connectedness – ability to interact with team members and outside collaborators who are geographically distributed at other sites
- Perceptual continuity – design that reinforces user interface metaphors, supports an intuitive "easy to learn, simple to use" paradigm

3.3 iLoft Design and Features

The iLoft is designed to be a highly flexible physical space that incorporates new forms of public and personal technologies that augment patterns of work in which design teams engage. Working with computer scientists at both institutions, the authors sought to change the way in which digital technology enters a physical design workspace so that it is more suited to patterns of work designers exhibit. Greater information mobility across devices, affordances for multiple simultaneous user interaction, embedded persistence of digital information, and increased "awareness" for integrated systems are just a few characteristics of the space and its technological infrastructure. Increased physical flexibility of the space, e.g. mobile interactive displays and wireless laptops, has presented interesting design challenges and at the same time has increased the versatility and appeal of the space.

The iLoft is still currently in a prototypical form. Major components deployed so far include:

LightBox – a highly-mobile, aesthetically designed interactive rear-projection system that works in conjunction with the PointRight and MultiBrowse components of iROS

GroupBoard – a sketching system for distributed design teams that uses a single iSpace-enabled pen input to write on real paper, select between multiple views of other designers' sketches, and issue commands. Each modality is determined by the location of the pen on the interface surface, and each participant can choose to view any other participant's work

CurveBoards – rollable whiteboard surfaces that are slightly curved and can be rolled around the iLoft as needed. Each of these whiteboards is fitted with a pen capture system, enabling them to record any pen strokes marked on their surface and later make them available for retrieval

TableBoards – round, collapsible tables that incorporate whiteboard material on their table top in support of unplanned discussion sessions

Videoconferencing system – not yet integrated into the iROS infrastructure, this unit serves as a basic connection between the iLoft and other sites. Future plans include integrating this device with the iROS infrastructure so that it can receive commands through the EventHeap

3.4 Migration to the 310loft

The iLoft was conceived to be a resource that attracted engineering teams by offering advanced technology capabilities. Some of the ideas embodied in it, however, have begun to migrate[21] to existing project spaces that support design team activity at Stanford, including design lofts associated with the ME310 (Design with Corporate Partners) and ME218 (Smart Product Design) courses. In these graduate level courses, the iSpace team has deployed the WorkspaceNavigator system so that student teams can use it in their course-related activities. Comments from faculty and students indicate that the act of integrating information technology into the physical workspaces that they use is a key factor encouraging their use of the tools. From a research data collection perspective, this is especially exciting, as it means the iSpace instrumentation has begun to permeate the infrastructure of the design community. By affecting the landscape of design at Stanford, the iSpace technologies are making it easier to acquire significant amounts of longitudinal data regarding their use in real engineering design activity without requiring direct data collection methodologies. While the authors and their colleagues are only beginning to explore the possibilities this presents, it does appear to be a major breakthrough for the field.

4 Preliminary Results

The iLoft design drew heavily on understandings about the ways that designers behave, as reported in the design research literature as well as the author's direct experience. Implementation of the iLoft provided software developers an unusual opportunity to build interfaces for a user community whose typical practices were fairly well understood. The requirements for physical flexibility and integration of digital media with physical inputs forced them to confront unanticipated issues. This opportunity proved to be highly motivating for the developers who would otherwise be forced to make assumptions about required capabilities for their projects.

Initial iLoft use has already yielded a large number of suggestions for changes to software applications. Designers using the space have been impressed with the altered physical design of elements to promote flexibility, as with the lightBox mobile interactive display devices and PointRight's ubiquitous control of a cursor across all devices in the space from any single device. Design students have also submitted a number of suggestions for further changes and additions, however. These suggestions, and general enthusiasm for the project, have led the authors to contemplate developing a project-based design course centered on the design of the iLoft.

A detailed study of one particular aspect of the iLoft – information Persistence, as provided by the WorkspaceNavigator tool – is ongoing in the ME310 loft. This study seeks to establish the relationship between such capabilities and increased design team performance. Results from this study will be reported elsewhere.

5 Conclusions and Future Work

The development of technologically augmented spaces for design teams presents new opportunities for data collection in design research. Instrumentation of such spaces to enable automatic data collection could address a longstanding problem in design research, i.e. difficulty in collecting *in situ* data on design team activity.

Neglected in previous design research, there is a growing need to consider how digital information enters the design workspace and the affordances it does, or does not, provide. To do so in the face of a diverse tapestry of emerging technologies will likely require a variable based approach in characterizing technology affordances.

Currently available information technology devices (e.g. notebook computers and personal digital assistants) have limited utility in team collaboration environments. When they are integrated within a larger context of an interconnected framework they can properly support design team activity. The switch to a framework in which spaces, not devices, are the smallest unit of consideration, will lead to new forms of technology products that will no doubt affect the physical and experience design of future engineering design tools.

The authors note that it would impossible to conduct development and research on this scale and across this range of technical and design process related issues without a collaborative interdisciplinary effort. The iSpace project has been remarkably successful in establishing working collaborative relationships across departments and continents in pursuit of its agenda. Regular communication (often by videoconference) between partnering groups, exchange of students between CDR and the Computer Science Department at Stanford, and a semi-annual collaboration workshops were key success factors in this collaboration. As such, the authors are using their own experiences in distributed team collaboration to develop ideas for new research directions the iLoft project may take in the years ahead.

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