KEYPHERSES: Internet design, design teams, communication media, knowledge sharing, learning rate, performance metrics

1 Abstract

The deployment of complex systems is an exponential function of their conceptual complexity. This rule-of-thumb is derived from our experience with the design and deployment of complex mechatronic systems (vehicles and aerospace); concurrent engineering systems (manufacturing of complex assemblies) and learning environments for teaching people how to do global, team-based, design-deployment. We have concluded that the limiting variables for team performance are the rate-of-learning they can “collectively” sustain and their ability to reuse-prior-experience when starting new projects. Net performance is then a function of the teams baseline knowledge-sharing capability and rate of learning. Both variables are, in turn, a function of their willingness to communicate and the technical infrastructure available to support communication. In this “position paper” we wish to share some of the key experiences that have lead to this proposition and our research agenda.

2 Introduction to the Position Paper

In the design community, the Internet is predominately used in one of three modes -- as an interpersonal communication medium, as a knowledge capture archive and as a knowledge retrieval medium. Much work in concurrent engineering and agent-based design make use of the Internet as a communication medium [1]. The Internet significantly reduces time and distance barriers in comparison to other media. Moreover, it is platform independent and data independent. Designers can digitally exchange any kind of data “anytime, anywhere.” The medium itself affords an opportunity to capture the data while it is communicated and several groups have begun to use the Internet as a design capture and retrieval medium [2]. The main purpose of such a usage has been to save the design data for use at a later time. Numerous design software tools have been developed to capture not only data communicated to others but also to record the designer’s own thinking as is the case for electronic engineering design notebooks [3]. The goal of this position-paper is to provide a selective overview of current research, “snapshot for discussion,” on internet-based design tools and design team performance metrics under study by the Stanford Center for Design Research (CDR, http://cdr.stanford.edu), and more recently by the Stanford Learning Laboratory (SLL, http://learninglab.stanford.edu).
3 CDR Design Philosophy

Figure 1. Ten years of formal experimentation have shown us those six steps, or levels of design environment sophistication, are required for sustainable design team performance improvement. The first three steps (1,2,3) are broadly familiar and well represented in the research literature. They relate to the tools, tricks and management of design activity day-to-day, including concurrent engineering. In contrast, steps 4,5,6 are largely neglected in commercial design activity and have only lately become the subjects of formal experimentation. Each step relates to how Internet technology can be leveraged to provide design teams with a new performance baseline for their own work through design knowledge re-use.

Ultimately, the goal of design research and design tool development is to improve design performance. In the past, attention has been focused on improving design performance within a self-limiting design cycle that brought new teams to the same baseline and blank canvas (steps 1,2,3 in Figure-1). At CDR, we have come to believe that sustainable performance improvement requires an expanded view of the design cycle, one that includes steps 4, 5, and 6 in Figure 1, steps that affect the baseline as well as performance as a rate effect. The expanded design cycle is concerned not only about design performance improvement but also about sustaining the capability of the next design team, such that they have a higher starting performance level for the inevitable design iteration. The Internet makes steps 4, 5, and 6 feasible. Attaining those steps does, however, require considerable effort and insight. This is especially true for traditional design tools that require an explicit and usually large effort by the designer to capturing and/or re-use previous product knowledge.

As a result, these tools tend not to be used by design teams unless there is a management mandate to do so and even then the results are meager. Our study found that while formal design data is often captured efficiently, it has surprisingly little utility, especially to people outside the immediate project team. The data represents bits and pieces of tacit knowledge only decipherable by those with an adequate contextual frame of reference. Even when these systems capture a large amount of related contextual data, it requires an unrealistic amount of time and effort for one to re-create the original meaning of the data due to its overwhelming volume and cryptic nature. Nonetheless, recent research at CDR has found that, with properly designed interfaces, the Internet may be used as a medium to induce designers to
naturally put their tacit knowledge into a more explicit format, one that is understandable to people outside of the project. These encouraging results have only come after long insistence that the designer interface must be “effortlessly transparent” during the capture phase as a prerequisite for “effortless re-use.”

4 Internet Design Media in Existing Media Mixes

Figure 2. Internet design media are highly specialized and diverse when mapped to a media utility space defined by “interesting to the designer versus expedient for the designer to access” and “synchronous versus asynchronous” access. The complexity of this design support space reflects the inherent complexity of design synthesis itself.

A first step in understanding how Internet media are likely to affect design team performance is to analyze the way media are used in design practice. Our study of design communication patterns within globally distributed teams yields the media map in Figure-2. It classifies design communication and media into three categories. These categories delineate why different modes of communication are used. For example, some modes, and media, are better for dissemination of established design ideas while others are better for conceptual design communication. These classifications help identify where Internet-based media should fit with respect to alternative media mixes. Note that the media do not always fall cleanly into one category or another. The dimensions include:

- **Synchronous** (time–coordinated) versus **asynchronous** — inventive conceptual design dialogs take place more readily in synchronous media; detailed design is well supported by asynchronous media.
- **Symmetric** (peer–to–peer) versus **asymmetric** (in terms of access to and control of expressions in a given medium, say a shared drawing surface) — conceptual
design is most often found in symmetric media; sharing of design detail is better supported by asymmetric media.

- **Expedient** versus **interesting** — expedient media are reliable, ubiquitous, and are the default ‘fallback’ choices of designers when time critical communication must take place; interesting media may add functionality to the communication mix, but are best used as part of a media cluster because they are typically not as reliable or accessible.

5 A “snapshot” of CDR Internet-Based Design Capture & Re-use Tools

According to a yearlong study by McKinsey and Co. [4], the most precious corporate resource in the next two decades will be talent. The use of talent, embedded in individual designers, is critical to design team performance. Unfortunately for those involved in product development, when designers leave the project, so does their knowledge. Conversely, it takes an enormous effort for a newcomer to pick up tacit design knowledge. Internet-based tool to capture, store, and access project specific knowledge helps in both aspects. We have focused our development efforts on helping new designers integrate into the team and project. This task constrains the own design support requirements sufficiently to allow for rapid development and evaluation. By collecting, organizing, and broadcasting critical design information, new team members can quickly bring their full talents to bear.

5.1 "Hunter-gatherer", a transparent capturing medium

We have been developing software that is expected to work without interfering with design activities – a transparent medium per se. We are calling it the ‘hunter-gatherer.’ It takes advantage of the individuality of designers and the connectivity of computers. It automatically gathers project related files sitting on the individual designer disk drives, and puts them in a shared file space. A pilot system was implemented and studied with one product development team. At first, it was merely extra files pace for the team to share information. It was not used at all. However, after making automatic backups of their files available over the Internet, the situation began to change in terms of increased usage and perceived value to the user. Further development is now underway to extending this agent in the following ways: 1) issue periodic email notifications regarding new and modified files; 2) produce full text indexing and searching of all documents, and browse by multiple criteria; and, 3) create quick, visual ‘thumbnail’ browsing documents.

5.2 "Recall", automatic pen-stroke indexing of audio/video

Indexing of audio and video information in design for re-use has been resource intensive and behaviorally burdensome. For example, approaches to indexing videotape typically require a time stamped transcription of the audio. For a source tape of one hour's duration, the transcription process can easily take over four hours. In approaching the design of a computer mediated indexing system to eliminate transcription, called "Recall", we took advantage of the designers’ transition between Internet genre to produce a “media mix” that binds the relationships between sketching and conversation, both verbal and gestural, to the fundamental strokes of the sketch. We use the sketch itself to provide an automatic index of informal contextual knowledge related to the creation of the sketch itself. Time-stamped sketching strokes give the computer a workable pre-text for formalizing the tacit knowledge stream. Accordingly, video and audio data streams are captured and synchronized with the sketch capture sub-system. Time-stamped strokes provide pointers to time offsets in the video and audio. In other words, the user can select an element of the drawing that will be automatically linked to the conversation that took place before and after the creation of that
particular aspect of the drawing. The Internet then allows this information to be distributed globally and accessed asynchronously.

5.3 Utilizing domain knowledge for indexing and retrieval of informal information

One member of the new breed of engineering design tools is electronic design notebook, an electronic version of the traditional engineer's logbook. Like traditional logs, electronic design notebooks are intended to capture design information as it is generated, providing a rich, unfiltered and sharable electronic history of the design project. These informal notebooks allow design teams to share entries with each other over the Internet. The shared history in such notebooks is of particular interest because of its potential for re-use.

A notable characteristic of the design language used in electronic design notebooks is that it constantly evolves over the life of a project, reflecting the nature of the design process itself. While many tools exist for indexing and retrieval of text documents, these methods operate on objective parameters such as word frequency, with little use of context or meaning. Such traditional information retrieval systems have difficulty understanding that a part referred to as a “thingamajig” early in the design process can be called “lead screw” by the end of project. At the CDR, we examine the addition of context to constrain traditional, generic search to the design domain, while effectively maintaining this context to accurately illustrate the changes in a design. The approach we take is to enhance existing information retrieval techniques with design-specific thesauri. This approach both helps limit search to the design domain, while expanding search to handle evolving terms. We are currently looking at ways to extract these thesauri automatically using techniques from computational linguistics. This machine approach allows thesauri to be updated and maintained flexibly throughout the life of a design project.

6 Discussion and Conclusion

Much of the research concerned with knowledge management is based on idealistic assumptions regarding the behavior of real people in real organizations. It assumes that people are, by default, open and willing to share and receive potentially useful knowledge. While this may be true for some organizations such as designers in training in a University engineering class, it is clearly not true for most commercial organizations. We must also recognize the limitation of our studies in their concern with a relatively small organization (approximately 40 designers in an environment that typically includes about 100 individual participants). In organizations with relatively small number of people where every one knows every one else, it is possible to exchange knowledge through direct interaction. It is easier, but by no means assured; that mutual trust can be established based on personal relationships. In larger organizations, the complexity is vastly different and the chance for deep personal co-commitment is diminished. Ad hoc exchanges within one’s personal network do happen, but systematic knowledge sharing usually requires brokering through people or technology. Along with brokering come issues such as knowledge identification, verification, and validation.

We hypothesize that all organizations, large and small can benefit from the implementation of a central knowledge capture and re-use infrastructure, a core technology for sharing and learning from each other, peer-to-peer. In large institutions (greater than 500 people) this infrastructure will have to be explicit and managed separately from the design team support infrastructure. For smaller institutions (less than 200) the infrastructure is no less important, but may not require or even be advanced by the use of a separate management.

References