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IDRAK: SUPPORTING DIGITAL SOCIALIZATION IN ENGINEERING DESIGN PROJECTS

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1. Introduction

The management of knowledge has long been recognized an important source of learning and innovation for a firm [Nonaka et al. 2000]. The knowledge and skills that a firm possesses are essential for developing new products, processes, and services, as well as for improving the effectiveness and efficiency of existing practices [Nonaka et al. 2000, McMahon et al. 2004]. Admittedly, a simplistic dichotomy differentiates tacit from explicit knowledge: tacit knowledge is intuitive, experimental, and based on heuristics, whereas explicit knowledge is structured and coded in some formal way. The dynamic interaction between tacit and explicit knowledge is the basis of Nonaka et al.'s (2000) knowledge creation theory, which postulates four complementary modes for knowledge conversion: tacit into explicit knowledge (externalization), explicit into tacit knowledge (internalization), individual tacit into group tacit knowledge (socialization), and separate explicit into systematic explicit knowledge (combination). Socialization involves sharing tacit knowledge without attempting a priori to codify that knowledge [Nonaka et al. 2000]. It includes processes such as conversations, storytelling, and apprenticeships, which foster collaborative working, enhance learning and innovation, help to diagnose problems, construct shared understandings, and ultimately help to build an identity or sense of community of practice [Nonaka et al. 2000]. In contrast, externalization documents tacit knowledge into rules, specifications, drawings, and formulae [McDermott 1999].

Organizations have made significant efforts to externalize knowledge, such as by developing company manuals and handbooks. Advances of digital technologies have partially shifted this effort to digital media, including electronic databases and knowledge repositories. These systems codify, organize, and store tacit knowledge to help users search, retrieve, assimilate, and disseminate knowledge when needed [McDermott 1999, McMahon et al. 2004]. Scholars have noted however limitations in efforts to codify knowledge [e.g., McDermott 1999, Erickson and Kellog 2000]. First, these efforts tend to reinforce existing practices, but fail to encourage people to think together, share insights, and generate new knowledge [McDermott 1999]. Second, they tend to assume that all types of tacit knowledge can be codified, but fail to capture the contexts in which the knowledge was originally embedded and will be eventually used [Erickson and Kellog 2000]. Third, they ignore users' lack of time to search for available knowledge and hardly recognize users for their contributions to knowledge repositories [McDermott 1999]. Fourth, they excessively focus on the knowledge in detriment of focusing on the community of knowledge users [McDermott 1999].

Research in the management of engineering design has long emphasized the importance of tacit knowledge sharing [e.g., Poli et al. 1992, Zaychik and Regli 2003, McMahon et al. 2004, Sim and Duffy 2004]. An important share of engineering design knowledge is tacit [Konda et al. 1992, Zaychik and Regli 2003], and exchange of tacit knowledge from the early design stages can speed up design

work and increase design quality [Poli et al. 1992]. Ad hoc socialization processes do not guarantee, however, effective communication between participants if they have different occupations and working languages, and lack understanding of what knowledge to share [Carotenuto et al. 1999].
Clearly, this problem matters to engineering design of projects where participants come from various communities of practice. Projects are comissioned by the client to a set of firms, including design consultants, contractors, and suppliers, that work together over the project time. The extent to which these firms remain together from project to project is limited by variability in product design, in procurement practices, and in project location. Given the 'social' nature of engineering design [Bucciarelli 1994], it matters to understand how to best facilitate the exchange of tacit knowledge across firms' boundaries from the early design stages of projects.
The fact that design participants are increasingly digitally networked through centralized web-based extranets [CICA 2002] merits investigation on how digital technologies can enhance cross-firm socialization. In the UK, for example, about six main application service providers – i.e. commercial companies specializing in developing, hosting, and managing project extranets – were operating in 2002 [CICA 2002]. Extranet applications offer digital features to support engineering design work, such as ability to red line drawings, calendar facilities, auditable paper trail, and digital security. They also enable project participants to post and retrieve codified knowledge, such as specifications and drawings, requests of information, meeting minutes, and schedules and budgets, yet have shied away from offering sophisticated digital socilization features. Research suggests that rigid communication structures militate against the exchange of tacit knowledge, which requires instead the voluntary coming together of people to negotiate shared meanings [Konda et al. 1992]. Here, we set off to investigate the extent to which adding a 'social' dimension to project extranets can facilitate cross-firm transfer of tacit knowledge at the early engineering design stages of projects. In the remaining of this paper, we first summarize the theoretical underpinnings of digital socialization. Then, we present IDRAK, a proof-of-concept of a digital platform for supporting cross-firm socialization in engineering design projects. Finally, we discuss our strategy to validate IDRAK.

2. Digital Socialization

Research on computer-supported collaborative work (CSCW) has examined how mutual relationships or interdependencies between individuals are constructed and established as social processes, and in what ways digital media can help or hamper these processes [Carotenuto et al. 1999]. Researchers define conversations as personally motivated social processes for eliciting, unpacking, articulating, applying, and re-contextualizing knowledge [Thomas et al. 2001]. Conversations can instantiate instrumental as well as expressive communication needs [Thomas et al. 2001]. Instrumental communication aims to accomplish tasks related to immediate organizational goals through well defined formats; it happens in specific contexts and includes specific information (e.g., job offers, invoices, proposals, and contracts). In contrast, expressive communication is motivated by personal or social aims to share experiences, indicate agreements, and be humorous (e.g., hallway conversations, informal meetings, scrawled notes, and e-mails about non-business issues) [Thomas et al. 2001].
Researchers have expressed concerns that many digital communication systems take for granted that users interact simply because the environment makes it technologically possible, while neglecting the social dimension of interaction. Current digital systems, such as e-mail, chat rooms, bulletin boards, and discussion forums, don't do a good job to help users keeping conversations on track, getting timely replies, and knowing who (or whether anyone) is listening: "in the digital world we are socially blind" [Erickson and Kellogg 2000]. Rather, digital networks ought to foster the development of virtual communities of practice – or of interest, purpose, or passion – spanning boundaries of work groups [Carotenuto et al. 1999]. Networks should help people to interact and feel integrated (especially new workers), share experiences, expose tacit knowledge, make recommendations, build personalized relationships, and discuss a wide range of topics; in other words, digital socialization should generate 'Socio-Technical Capital', a resource (such as artifacts) produced as a side-effect of repeated technology-mediated social interaction that accumulates and gets available to support other interactions [Girgensohn and Lee 2002].

The theoretical underpinnings of CSCW primarily stem from principles in physical socialization that, in turn, are informed by two grand theories of communication – media richness theory and social presence theory. Media richness theory explains a medium's capability to convey certain types of information. This is a function of the medium's capacity for supporting immediate feedback, multiple cues, language variety, and personal focus of sources [Connel and Mendelsohn 2001]. Along these dimensions, media can be ranked in order of decreasing richness as follows: face-to-face, video, telephone, e-mail, addressed written documents, unaddressed written documents, and formal numeric text [Connel and Mendelsohn 2001]. On the other hand, social presence theory refers to the degree to which a communication medium permits communicators to experience others as being psychologically present, or the degree to which a medium is perceived to convey the actual presence of the communicating participants [Connel and Mendelsohn 2001]. Nonverbal cues, social situation norms, and rules play a significant role in social presence [Connel and Mendelsohn 2001].

Our empirical findings from a case study within the context of a major investment programme [El-Tayeh and Gil 2006] suggest that e-mail and commercial extranets lack the ability to enhance socialization across the digitally networked design participants. A cross-fertilization of the case study findings with the literature review on digital socialization forms the basis of our proof-of-concept to 'socially' enhance digital networks that already support engineering design work.

3. IDRAK: a Proof-of-Concept for enhancing Socialization in Engineering Design

We termed IDRAK, an acronym for Internet Dialogue and Repository for Acquired Knowledge, to our proof-of-concept of a 'social' web-based system to support engineering design in projects (Figure 1). The words 'Dialogue' and 'Repository' reflect respectively the synchronous and asynchronous knowledge exchange features offered by IDRAK. Semi-synchronous approaches encourage a greater range of responses [Hollan and Stornetta 1992]. 'Acquired Knowledge' expresses the ability of design teams to reuse tacit knowledge between projects.

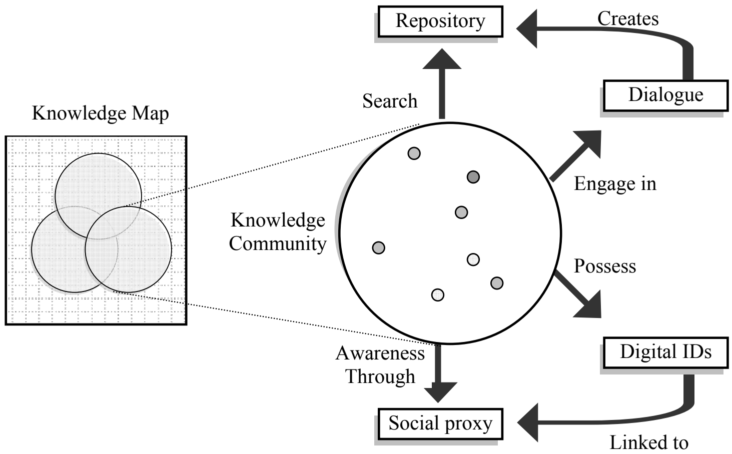

Figure 1. IDRAK Conceptual Framework

The conceptual framework underpinning the implementation of IDRAK pieces together the following capabilities:

- *Knowledge Map*: It links a set of knowledge 'communities', each aggregating groups of users with shared practices and similar interests [Girgensohn and Lee 2002]. Digital communities facilitate 'interaction' by raising users' awareness to others' competences [Erickson and Kellogg 2000].
- *Digital IDs*: It enhances the visibility of users' digital presence. Each user holds a persistent digital identity and profile. Digital IDs help users to recognize other registered users and build a reputation on the digital space [Girgensohn and Lee 2002].

- *Social Proxy*: It aims to provide users with cues to convey social awareness through the use of graphics. It enhances user awareness and recognition for other users' knowledge, situation, availability, and activity [Isaacs et al. 2002]. IDRAK allows users to make or not themselves visible since too much visibility online can detract users [Erickson and Kellogg 2000].
- *Dialogue*: It allows users to engage in synchronous communication to facilitate the creation of common grounding [Hollan and Stornetta 1992].
- *Repository*: It codes and collates dialogues into a searchable repository of contextualised conversations to facilitate tacit knowledge dissemination [Erickson and Kellogg 2000].

3.1 Overview of IDRAK's Graphic User Interface (GUI)

We implemented IDRAK as a Rich Internet Application (RIA) that visually displays all information in a single-screen made up of a bottom and top user-interface panels (Figure 2). The top panel consists of two main elements: the navigation bar and the social proxy. The navigation bar has two purposes: First, it allows users to customize some settings, including bandwidth characteristics (e.g., modem, ADSL, LAM, Dial-up) and the color of choice (this color will show both in the people-like icon in the social proxy and in the text entries in the instant dialogue box). Second, it provides users with a ring button to trigger a sound alert on the desktop of other logged-in users. IDRAK acknowledges that logged-in users may have the IDRAK window minimized on their computer desktop while they work with other applications. A logged-in user can therefore use the 'ring' button to grab the attention of other logged-in users. This is similar to procedures to start a telephone conference call except that IDRAK users control the number of times to ring.

The social proxy is a graphical social navigation approach for social awareness [Erickson and Kellogg 2000]. It includes two components, one 'active' and one 'passive.' In the 'active' component, logged-in users are depicted as movable, semi-transparent colored, people-like icons. These icons turn opaque and graphically propagate a sound wave when a logged-in user types in the IDRAK window. If a user is logged-in but working (typing) on another application her icon will stay semi-transparent and will not display a sound wave. Further, when a logged-in user is active, i.e. typing in the IDRAK window, the people-like icon moves gradually to the foreground and the size of the icon gradually expands. Conversely, the people-like icon gradually moves to the background and shrinks in size once a user stops typing. This feature conveys a sense of the availability of logged-in users to engage into a digital conversation. The 'passive' component of the Social Proxy further enables users to make others better aware of their availability to dialogue through text- and color-based cues, including 'online' (blue), 'away' (white), 'be right back' (green), and 'out to lunch' (orange).

The bottom panel of IDRAK consists of two main elements: one holds the Digital ID and Knowledge Map, whereas the other holds the Instant Dialogue and Knowledge Repository. The Digital ID and Knowledge Map is an interactive 'yellow-pages' feature [Girgensohn and Lee 2002] to which we added real-time search capabilities. Hence, the Digital ID displays information entered by users when they register with IDRAK, including name, job role, contact details, and knowledge profile in terms of experience, interests, and capabilities. The registration act also requires a user to graphically plot herself into one or more communities in the knowledge map. The position of the dot in relation to the geometric centre of the intersection between knowledge communities conveys information about the extent to which a user feels she belongs or not to each community. Users can find out the position of registered users in the knowledge map by dragging a 'radar square' over the knowledge map — IDRAK automatically displays in real-time a list of all user names within the radar boundaries, and the user can then click on any name to retrieve the Digital ID.

The Instant Dialogue and Repository enables logged-in users — belonging to the same or different communities — to engage in synchronous and asynchronous conversations (Figure 3). The Instant Dialogue is a synchronous chat environment. Users that log in the middle of an ongoing conversation can familiarize themselves with the parts they missed by scrolling up and down the text in the chat box. Each color-coded text entry is preceded by the name of the user who sent it. The Instant Dialogue also displays automatically notifications when new users log in or out of IDRAK, as well as when a user changes her availability status in the passive social proxy. The 'Save' button in the Instant Dialogue box enables users to save all or part of a dialogue into the Repository, thereby allowing to document tacit knowledge within a rich context. IDRAK deletes automatically a conversation record from the dialogue box approximately 15 minutes after the last user has logged out. This feature gives the last user a chance to log in back again in case she changed her mind and wishes to save the conversation into the Repository; it also safeguards against unexpected lost connectivity.

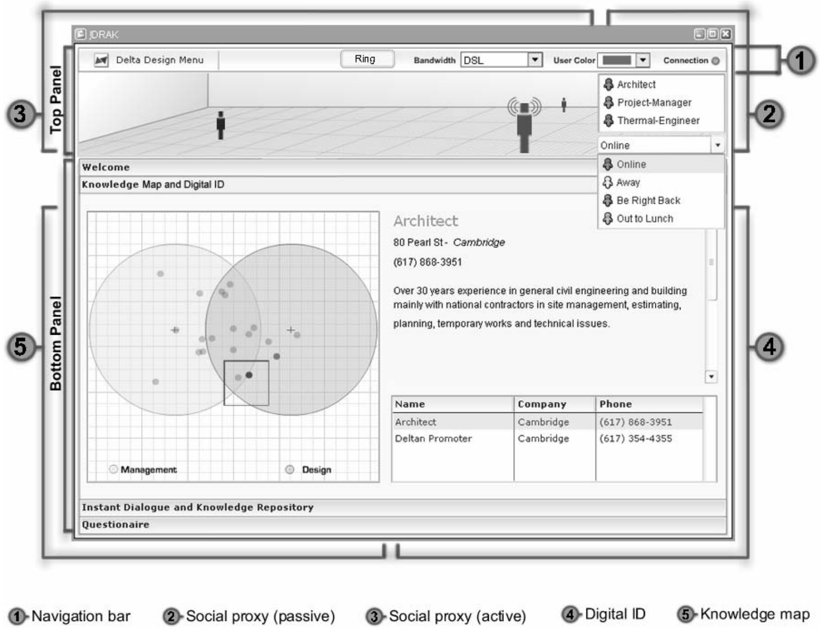

Figure 2. IDRAK's User Interface showing the Knowledge Map and a Digital ID

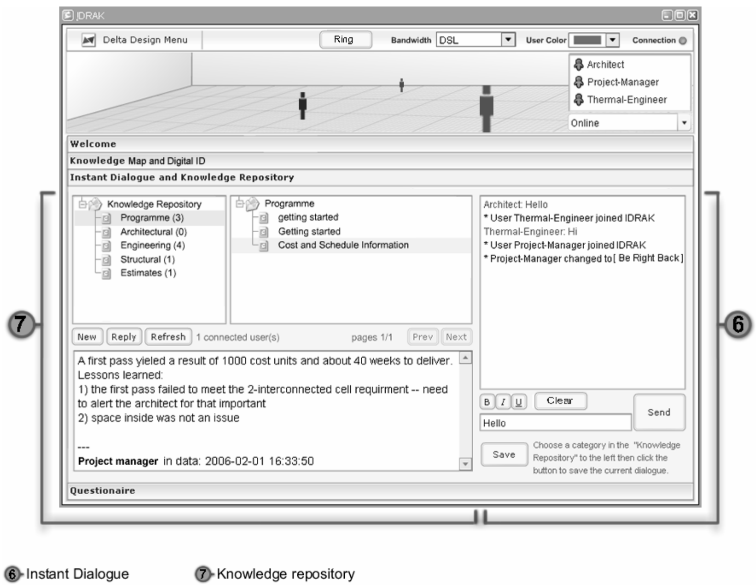

Figure 3. IDRAK's User Interface showing the Knowledge Repository and Instant Dialogue

The Knowledge Repository enables users to examine documented conversations as well as to engage into asynchronous conversations. The save button in the Dialogue is disabled by default to disallow users from documenting a (part of) conversation in the Repository without categorizing it first according to preset design ontology. IDRAK automatically enables the save button after a user completes the categorization task. A windows-type file explorer enables users to browse and retrieve documented conversations, displayed according to the ontology rules. The Repository also provides users with a box to type text. Thus, a user can asynchronously initiate a new conversation or reply to a documented conversation and get the contribution directly documented in the Repository. The Repository automatically creates a folder to document together all contributions related to a specific conversation, which is named after the first entry. Both the 'new' and 'reply' buttons in the Repository are disabled by default to disallow contributions outside the ontology rules. In effect, IDRAK requires users to highlight a class in the Repository, or highlight a class and a documented set of dialogues, before enabling respectively the 'new' and 'reply' buttons.

4. Validation Strategy

We plan to validate the usability of IDRAK in a laboratory setting where we will mimic the demands of engineering design work. Broadly, the meaning of usability has been associated with "quality in use" [Bevan 1995], but more specifically it is defined as "the effectiveness, efficiency and satisfaction with which specified users can achieve goals in particular environments" [ISO 1998]. Hence, we will instantiate IDRAK to play online the Delta Design exercise (Figure 4) — a known board-based exercise where a four-element design team (structural engineer, thermal engineer, project manager, and architect) face the challenge of developing a 2-dimensional conceptual design of a building suitable for, and attractive to, the inhabitants of the imaginary Deltoid planet [Bucciarelli 1999].

Each participant in the Delta design exercise is given ex-ante a set of instructions to prepare her role, including a generic exercise description and a role instruction. The latter informs each participant of her own design constraints, objectives, and rules to judge the quality of a design solution. The two engineers must ensure that the output meets their design criteria, the project manager must ensure that the output meets the budget and schedule, and the architect must ensure that the output meets aesthetic criteria [Bucciarelli 1999]. The four participants are instructed not to discuss their roles before the game starts. Throughout the exercise, the design team must place triangular red- and blue- colored tiles on a diamond-shaped grid to develop a conceptual design. The criteria underpinning each role shape each participants' preferences for a configuration, as well as for the number and color of the tiles and the way the tiles overlap. Participants are typically allowed up to 120 minutes to make tradeoffs and agree a solution.

A bespoken instantiation of IDRAK will provide a suitable environment to mediate online communication across the Delta design team. Each participant will operate from a different desktop computer to mimic a situation where the team stays geographically dispersed and unable to meet for the length of the engineering design session. We complemented IDRAK's capabilities by developing a digital board where users can pick and move tiles on a diamond-shaped grid. Further, we instantiated IDRAK with a small subset of the e-COGNOS ontology — an ontology on the semantics underscoring the content and interdependencies of documents used in engineering design projects to promote consistent knowledge management within collaborative environments [Zarli et al. 2000]. E-COGNOS comprises a set of process models that include main user profiles (e.g. project manager, architect, and structural designer), as well as a set of class diagrams to describe design tasks (i.e. site analysis, sketch design, programming, and estimating) and the relationships between tasks and outputs. We will try to assemble as many teams as possible to play the Delta Design exercise over the computer. Each test run is expected to generate synchronous Dialogues that users can save in the Repository. Hence, the last project teams playing the exercise can learn by searching the knowledge exchanges held and stored by the first teams.

Usability of an artifact cannot be directly measured, but can be operationalized into measurable objective and subjective attributes [Folmer and Bosch 2004, Hornbæk 2006]. Objective attributes focus on aspects of the interaction that are not dependant on users' perception, e.g. efficiency and learnability [Folmer and Bosch 2004, Hornbæk 2006], whereas subjective attributes focus on users' perception of (or attitudes towards) the interface, the interaction, and the outcome, e.g. satisfaction and attractiveness [Folmer and Bosch 2004, Hornbæk 2006]. We will use three accepted dimensions to comprehensively measure the usability of IDRAK: (1) effectiveness, (2) efficiency, and (3) satisfaction [e.g., Hornbæk 2006]. Effectiveness is "the accuracy and completeness with which users achieve specified goals" [ISO 1998]. We will measure effectiveness by evaluating both the degree of task completion and the quality of the interaction outcome from a user's perspective [Hornbæk 2006]. Efficiency is "the resources expended in relation to the accuracy and completeness with which users achieve specified goals" [ISO 1998].

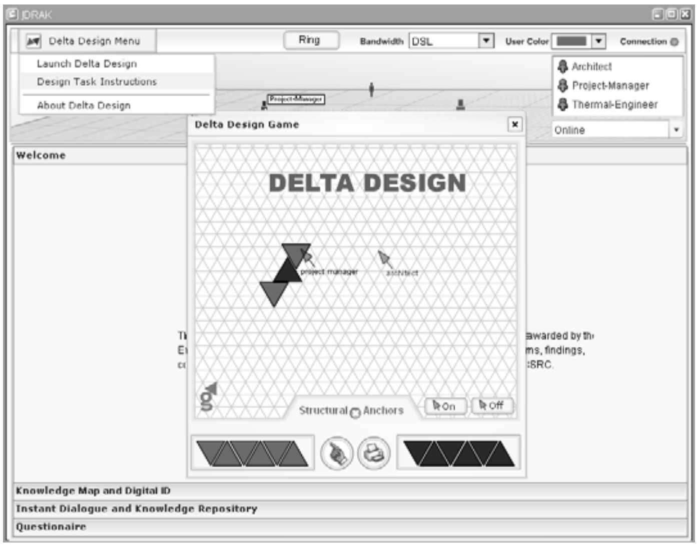

Figure 4. Delta Design Window in IDRAK's User Interface

We will measure efficiency by evaluating usage patterns to solve tasks and resources that users expend in communication efforts [Sauro and Kindlund 2005, Hornbæk 2006]. Finally, satisfaction is "the freedom from discomfort, and positive attitudes towards the user of the product" [ISO 1998]. We will measure overall satisfaction by evaluating system usefulness, information quality, interface quality, and perceptions of outcomes/interaction [Hornbæk 2006, Lewis 2002].

We will mix and match three usability-inquiry methods to collect data: a standard questionnaire, semi-structured interviews and observations, and analysis of actual logging use. First, we will request users to complete online, at the end of each test run, the standard PSSUQ questionnaire [Lewis 2002] to collect data on satisfaction., including measures of quick completion of work, ease of learning, high-quality documentation and online information, functional adequacy, and rapid acquisition of productivity [Lewis 2002]. Second, we will interview users to collect data on specific subjective measures of effectiveness and efficiency. Third, we will code and analyse actual conversational data to objectively measure efficiency, using coding schemes developed to validate research on instant messaging and persistent chat prototypes [Isaacs et al. 2002]. We expect to report back on our findings in one year time, as well as discuss the limitations of assuming repeatability of engineering design projects and a contractual environment that welcomes inter-organizational digital collaboration.

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