Using Digital Socialization to Support Geographically Dispersed AEC Project Teams

Amjad El-Tayeh[1] and Nuno Gil[2]

Abstract: In the field of knowledge management research, socialization means to convert individual into group tacit knowledge. This process matters from the outset of an architecture, engineering, and construction (AEC) project to enhance collaborative work. Face-to-face meetings and phone calls undoubtedly facilitate socialization. However, meetings can be hard to timetable and expensive when AEC teams are geographically dispersed, whereas phone calls are cheap but offer limited capabilities for problem solving. Further, both media are not good at supporting asynchronous socialization. This study investigates the extent Internet-based media can promote cross-firm socialization and enhance collaborative work. The cross fertilization of findings from an exploratory case study with theory in computer-supported collaborative work (CSCW) informs the development of a conceptual framework on digital socialization. This framework underpins IDRAK—a proof-of-concept of a rich Internet application prototype to promote socialization in AEC projects. Our main contribution is the design of a novel methodology to evaluate the usability of digital systems to support socialization at the early design stage of an AEC project. The results from our lab experiments suggest that IDRAK can satisfactorily and efficiently enhance collaborative work. However, more research is needed, first, to evaluate the effectiveness of IDRAK to improve design quality and asynchronous socialization; and second, to investigate how other CSCW features can improve the performance of IDRAK-like systems.

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Introduction

The management of knowledge has long been recognized an important source of learning and innovation for a firm (Nonaka et al. 2000). 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 the knowledge creation theory (Nonaka et al. (2000)). Nonaka et al. term *socialization* to the conversion of individual into group tacit knowledge without attempting a priori to codify, or externalize, knowledge. Socialization includes conversations, apprenticeships, and storytelling. These mechanisms help individuals work collaboratively, build communities of practice (Brown and Duguid 1991), and develop "common ground," i.e., mutual knowledge, beliefs, and assumptions between conversants (Clark and Schaefer 1989).

Extant research elucidates how knowledge management practices can improve the performance of architecture, engineering, and construction (AEC) projects (e.g., Korman et al. 2003; Soibelman et al. 2003; Robinson et al. 2004; Al-Ghassani et al. 2006). The increasing complexity of designs has contributed for the replacement of the centralized master builder with project delivery systems that fragment design and construction responsibilities across a myriad of specialists (Yates and Battersby 2003). This evolutionistic organizational phenomenon limits each party's knowledge of the delivery process and design problems (Yates and Battersby 2003; Tsao et al. 2004). It also contributes to the surge of conflicts—often deleterious to project performance and product quality—occurring at the interface level when project participants lack understanding for each other's views of the world (Ankrah and Langford 2005).

One stream of research focuses on capturing tacit knowledge related to design criteria, construction operations, and maintenance of building systems, and then codifying it into computer tools that can assist practitioners in resolving design–construction interface problems (e.g., Korman et al. 2003; Soibelman et al. 2003). Other digital prototypes emulate best practices on how leading AEC organizations identify and define knowledge problems (Robinson et al. 2004; Al-Ghassani et al. 2006). The logic underlying these approaches assumes that individuals will voluntarily contribute know-how into—and retrieve it from—digital repositories.

Research suggests, however, that there are limits to the extent tacit knowledge can be externalized (McDermott 1999; Erickson and Kellogg 2000). These limitations include the failure of some knowledge databases to encourage people to think together, share insights, and contribute new knowledge (McDermott 1999); the difficulties to capture the contexts in which knowledge was originally embedded and can be applied (Erickson and Kellogg 2000); and the lack of users' time to contribute and search for available

[1]Assistant Professor, School of Business Administration, American Univ. in Dubai, P.O. Box 28282, Dubai, United Arab Emirates. E-mail: aeltayeh@aud.edu

[2]Lecturer (Assistant Professor), Associate Professor, Centre for Research in the Management of Projects (CRMP), Manchester Business School, Univ. of Manchester, Booth St. West, Manchester M15 6PB, U.K. E-mail: nuno.gil@mbs.ac.uk

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Table 1. Principles of Physical Socialization and Digital Implementation

Principle	Description	Digital implementation
Visibility of social information	Individuals need to draw upon their social experience and expertise to structure their interactions; excessive visibility can be detrimental	Random picture galleries (Girgensohn and Lee 2002); graphical-based chat (Erickson and Kellogg 2000)
Reputation of individuals	Individuals need to know about other individuals' identity and their past action to overcome the reluctance of individuals to cooperate and interact	Reputation mechanisms (Connel and Mendelsohn 2001; Jensen et al. 2002); predictive utility indicators (Jarret and Denis 2003)
Social awareness	Individuals need to understand how others' activities provide a context to one's own activity, including cues about availability and situation (is individual busy, away, or at lunch?), and knowledge (does individual have specific knowledge or knows who has it?)	Social proxies using sound and/or graphics to portray salient aspects of digital socialization (Tollmar et al. 1996; Erickson and Kellogg 2000; Isaacs et al. 2002)
Synchronicity	It facilitates the creation of "common grounding" by allowing to clarify in real-time possible misunderstandings and misinterpretation of ideas	Chat, video–audio links (Clark and Schaefer 1989; Halverson et al. 2003)
Persistence	It provides history and context that exist beyond the immediate here and now to develop long-term interdependent relationships	E-mail, bulletin boards (Karsten 2003; Girgensohn and Lee 2002)

knowledge (McDermott 1999). Efforts to codify knowledge therefore need to be complemented with mechanisms that can facilitate the voluntary coming together of people to exchange tacit knowledge, i.e., socialize, and negotiate shared meanings (Konda et al. 1992).

In the AEC sector, cross-firm socialization is promoted, for example, through partnering initiatives (Larson 1997). Partnering events such as meetings may fail, however, to enhance collaborative work when individuals have different occupations and working languages, only work together temporarily, and lack understanding of what knowledge to share (Carotenuto et al. 1999). Further, face-to-face meetings can be hard to timetable and expensive to organize when project teams are geographically dispersed. On the other hand, video–audio calls rarely support asynchronous exchange of tacit knowledge, and do not have capabilities to disseminate knowledge outside the conversation loop (Erickson and Kellogg 2000).

Increasingly, however, AEC firms stay digitally networked throughout project time using the Internet in general, and project extranets in particular, i.e., Web-based systems that link a number of different firms for facilitating the exchange and storage of documents. Extranets offer functionalities to structure the flow and archive of documents. They also enable users to red line drawings and control work through auditable paper trails. Yet, they are still incipient in promoting digital socialization.

Our study investigates the extent Internet-based media can promote cross-firm socialization across geographically dispersed AEC project teams. First, we review the principles of physical socialization underlying informal communication and impromptu conversations, and examine empirical findings from an exploratory case study on cross-firm socialization practices. Internet dialogue and repository for acquired knowledge (IDRAK), is then introduced a proof-of-concept of a rich Internet application for promoting cross-firm socialization. Finally, we evaluate the usability of IDRAK to enhance collaborative work at the early design stages of an AEC project, and draw conclusions.

Background

Literature in computer supported collaborative work (CSCW) critiques most available systems to support digital collaboration because they neglect the social dimension of interaction, taking for granted that participants interact simply because the environment makes it technologically possible (e.g., Erickson and Kellogg 2000; Kreijns et al. 2003). Researchers critique functionalities in commercial packages, such as e-mail, chat rooms, bulletin boards, and discussion forums, for failing to help users keep conversations on track, get timely replies, and know who (or whether anyone) is listening; as put by Erickson and Kellogg (2000) "in the digital world we are socially blind." These critiques underscore research to develop and evaluate new systems that can implement key principles of physical socialization (summarized in Table 1).

Research in CSCW has investigated in depth how digital media can help individuals construct mutual relationships and work collaboratively, and accordingly it has developed prototypes to promote socialization (e.g., Carotenuto et al. 1999; Erickson and Kellogg 2000; Connel and Mendelsohn 2001; Karsten 2003; Kreijns et al. 2003). This work matters as organizations across various industrial sectors increasingly resort to virtual teams as a means to hire and retain the best people regardless of location. [See Sessa et al. (1999) for a review of the various issues affecting the performance of virtual teams.] Recent data suggest that the "virtualization" of organizations (Handy 1995) is increasingly affecting AEC project teams (Taylor 2006).

Commercial digital applications to support virtual teams are of course on constant, and rapid, evolution. Skype, a proprietary peer-to-peer Internet telephony (VoIP) network, was hardly known when we started our work early in 2004, but its use is now quite popular (including with the industrial sponsors of this research). Skype per se does not meet the requirements of CSCW tools neither supports asynchronous communication, but paves the way to economically integrate voice/video with text- and graphically based digital platforms. Likewise, recent desktop client-server software, such as Groove.net and Lotus Notes SameTime, increasingly allow teams to create ad-hoc shared "workspaces," i.e., private virtual locations where users interact and collaborate through instant messaging and Web conferencing.

We observed that these new tools are being increasingly adopted by the virtual teams operating within the organizations that sponsored our research. Little is known, however, how this is impacting the performance of virtual AEC teams. Also, little is known about methods to evaluate those impacts. The work we

Table 2. Summary of Data on Cross-Firm Socialization Practices at the Research Site

Media	Pros	Cons	Data exemplar
Face-to-face meetings	Synchronicity, social interaction, rich context, support of artifacts	Time-consuming, close loop, ineffective when right people fail to attend	"The revised drawings and minutes that result from meetings cannot include any of the underlying knowledge and experiences needed to reach such decisions." (site manager)
Mobile/land phone calls	Synchronicity, cheap, practical, informality	Close loop, no persistence, lack of physical and video support	"I use phone because it has a more immediate response. Sometimes I send someone an e-mail and then pick up the phone and tell him I have just sent you this e-mail about this thing." (design coordinator)
E-mail messaging	Ease of use, familiarity, allows attachments	Ambiguity, liability implications, information overload	"E-mail is a lot clearer to a lot of people than other IT tools because it has been used extensively throughout the past 5 years in the construction industry." (design manager)
Socialization features of the extranet (team mail, project forum)	Both features were hardly used	Excessive visibility, liability implications, not user-friendly, poor fit with extranet usage protocol	"If it is worth being put there, then it is worth being said in a meeting or personally to somebody or recorded in some other manner [...] If we had nothing else then we would probably use it extensively, but it [project extranet] came to us in a later date than our existing tools." (project engineer)

present next advances knowledge along these two dimensions. We next summarize findings from an exploratory case study on socialization in an AEC environment, which informed the development of the specifications for our proof-of-concept prototype. We then present a novel methodology to evaluate the usability of digital systems to support virtual AEC teams, and apply this methodology to evaluate our prototype.

Exploratory Case Study: Socialization in an AEC Environment

The purpose of this case study was to investigate the view of participants in engineering design projects about the suitability of different channels to exchange know-how, including face-to-face conversations, phone (landline/mobile), e-mail, and project extranets. We used an interpretive approach because we were interested in uncovering the practitioner's perceptions rather than in quantitatively measuring the usage of each channel. Further, we did not apply rigorous coding techniques to the case study because its purpose was exploratory rather than building or testing theory (Yin 1984). To overcome individuals' biases, we built a sample of interviewees which included professionals with different job roles, such as project managers, design coordinators, engineers, architects, and subcontractors. We adopted a snowball tactic (Vogt 1999) to identify the interviewees, asking a respondent who else could complement her/his points of view.

The research setting was a capital expansion program commissioned by a British utility water company, which was more than halfway through when we started data collection. The utility company appointed a consultant to act as the overall project manager and engineering services provider, and signed a framework agreement with a joint venture company for detail design, construction, testing, and commissioning of new water and wastewater projects. We gathered empirical data through a series of one to two hours long, semistructured interviews, some of which involving multiple respondents and two interviewers. Our strict interview protocol included tape recording and transcribing all the interviews. We addressed the issue of reliability by triangulating interview data against documents and observations, including an in-depth walk-through of the adopted project extranet. We next discuss the respondents' perceptions about cross-firm socialization, summarized in Table 2.

Socialization through Face-to-Face Meetings

The need for project participants to get together regularly was spelled out in the contractual agreements, but firms were free to set up the format, frequency, and location of the meetings. Project participants felt that the advantages of meetings included: (1) speeding up decision making and problem solving; (2) providing a rich environment where people could show drawings and audio-video presentations; and (3) providing an environment that enabled professionals to be friendlier and more personal with their colleagues from other firms. A design coordinator illustrated how meetings helped to create "common grounding" (Clark and Schaefer 1989): "You can never replace them because a lot of the times the design engineer would be sketching things on paper and asking if this would solve the problem, and you cannot substitute this with e-mail or project extranet." On the downside, respondents pointed that meetings could be time-consuming, difficult to arrange, and ineffective if the right people failed to attend. They also felt that the know-how generated in meetings was hard to capture in the minutes.

Socialization through Telephone and E-Mail

Respondents characterized phone conversations as useful to clarify the technical and managerial issues emerging over project time. They also noted that phone conversations allowed discussing delicate issues in a nondocumented fashion, with fewer implications in terms of professional liability. They noted, however, that phone conversations had limited problem-solving capabilities because they lacked a shared visual support. To circumvent this inadequacy, respondents resorted to e-mail messages with attached drawings, sketches, and documents. Unlike phone conversations, however, respondents noted that e-mail exchanges could be slow and ambiguous. Hence, one respondent observed that e-mail was useful for confirming and clarifying issues, but less so for explaining and exchanging new ideas: "When you put some-thing in writing, that doesn't mean that people will understand the content. If I am writing an e-mail I tend to describe things in my own way. If I send this e-mail to someone s/he might fail to understand what I am trying to say." Further, professionals were cognizant that too much e-mail communication could be detrimental to collaborative work because people lacked the time to reply: "Sometimes I send someone an e-mail and then pick up the phone and tell him I have just sent you this e-mail about this thing (…) if I need a very quick answer the best medium is sometimes mobile phones not even landlines." We next investigate whether professionals used the extranet to socialize across firm borders.

(No) Socialization through the Project Extranet

The program administrators decided to adopt a commercial project extranet approximately one year after the start of the capital program. The functional features of the extranet helped project teams formalize the processes to verify and approve documents. In addition, the extranet provided three features for supporting cooperative work: "Team mail," "project forums," and "telephone directory." Team mail enabled the project participants to communicate via e-mail messaging, and the digital correspondence was automatically archived in one repository for future reference. The project forums worked as virtual meeting-places where users could communicate with each other and engage in open discussions. The telephone directory displayed data of individuals, including job role, employer, and contacts.

When the extranet was first introduced, project participants rapidly adopted its functionalities to mark up and exchange documents in real time, as well as resorted frequently to the telephone directory. In contrast, team mail and the project forum were infrequently used because, first, project participants felt uncomfortable about the extent that individuals in other firms could check the content of messages: "It is too visible as he [the consultant] can see everything on the extranet and that is not necessarily what we want [. . .] I think it should be used with things that are already decided, but not with the process of getting somewhere." Second, senior people were reluctant to embrace new media; as put by one project engineer: "I think this [low use of project forum/team mail] is just because people became comfortable and familiar with a specific way of doing things. The culture is not there yet."

Interestingly, the frequent use of the extranet to informally exchange documents across firms soon raised concerns with the program administrators who were unclear about the implications in terms of professional liability. Hence, administrators enforced a communication protocol to restrict its use. The consultant assigned a number of project engineers who acted as gatekeepers of messages getting in and out of the extranet. Likewise, the joint venture assigned a number of design coordinators and lead engineers who acted as gatekeepers of communication, respectively with the consultant and with subcontractors. A design coordinator explained the implications of the protocol: "The contract limits everyone's communication [. . .] until contracts are built in a way that enforces the use of the extranet in a different way, you will always find that its use will be restricted to a cycle of passing, commenting, and reviewing information."

Final Observations

Our findings suggest that practitioners resort both to meetings, phone calls, and e-mail to socialize albeit the possible implications of the latter in terms of professional liability. Without downplaying the importance of liability issues, we believe that the use of digital media to support problem-solving across virtual AEC project teams is likely to grow. On one hand, we find plausible that the more young blood enters into the industry, the more "digitally native" professionals will resort to digital socialization. On the other hand, commercial competition and resource scarcity increasingly force AEC firms to outsource work to professionals based in other countries. We therefore underpin our research upon assuming a contractual environment which encourages cross-firm digital socialization.

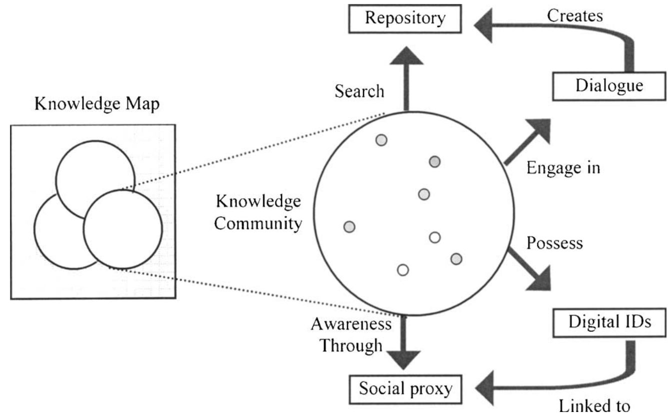

Fig. 1. Conceptual framework for digital socialization

There are three additional insights from the fieldwork underpinning the conceptual framework that we present next. First, we observed extensive use of e-mail to support knowledge exchange despite its inadequacy to promote rapid responses and inform the sender about the receivers' availability. It became a specification to develop a framework allowing for synchronous communication. Second, practitioners noted the inadequacy of digital "yellow pages" to help individuals rapidly search for subject-matter experts. It became a specification to develop a framework allowing for a graphical representation of individuals' profiles. Third, practitioners alluded to the benefits of synchronous communication despite its inadequacy to document the conversations. It became a specification to develop a framework allowing for documenting (parts of) digital dialogues into a searchable database.

IDRAK: A Rich Internet Application for Promoting Cross-Firm Project Socialization

The cross fertilization of our empirical findings and extant theory resulted in a conceptual framework to guide the development of digital socialization tools for supporting AEC vitual teams. This framework pieces together the following functional elements (Fig. 1):

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

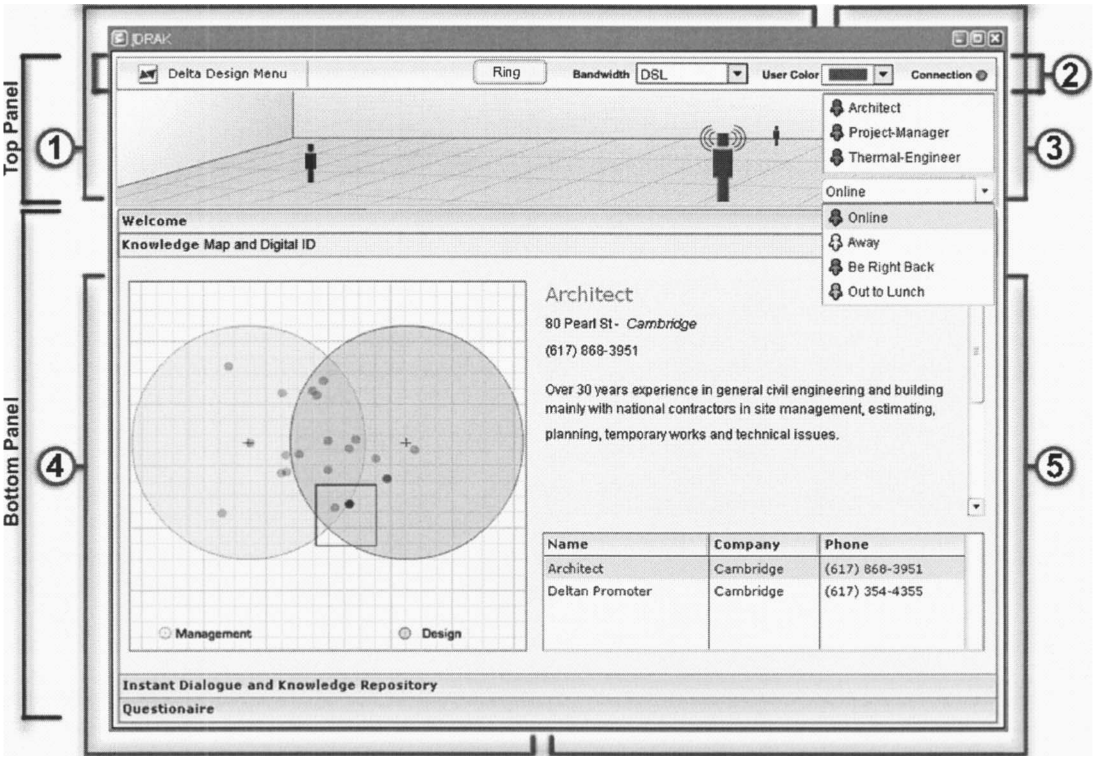

Fig. 2. IDRAK's user interface showing: (1) active social proxy; (2) navigation bar; (3) passive social proxy; (4) knowledge map; and (5) digital ID

- Social proxy: It provides users with graphical cues that convey social awareness and recognition for other users' knowledge, situation, availability, and activity (Isaacs et al. 2002). Social proxies should leave open to users the option of making themselves visible since excessive visibility can deter communication (Erickson and Kellogg 2000);
- Dialogue: It allows users to engage in synchronous text-based communication to facilitate the creation of "common grounding" (Hollan and Stornetta 1992); and
- Repository: It gives users the option to document parts of dialogues into a searchable repository for facilitating asynchronous dissemination of individual into group tacit knowledge (Erickson and Kellogg 2000). It also gives users the option to add additional observations to documented dialogues.

IDRAK: Implementing the Framework through a Rich Internet Application

We termed IDRAK to our implementation of the conceptual framework into a proof-of-concept prototype for promoting digital socialization across geographically dispersed AEC project teams. IDRAK is an acronym for Internet Dialogue and Repository for Acquired Knowledge. The terms dialogue and repository express respectively synchronous and asynchronous knowledge exchanges, whereas acquired knowledge expresses the need to help project participants gain awareness for others' know-how and inform others about their own expertise. IDRAK implements the conceptual framework through a rich Internet application that visually displays information in a single screen made up of two user-interface panels (Fig. 2). The top panel consists of two main functional elements: the *navigation bar* and the *social proxy*. The navigation bar allows users to customize some settings, including bandwidth characteristics, as well as the color of the social proxy and of the entries in the dialogue box. The navigation bar also provides users with a ring button to trigger a sound alert on the desktop of other logged-in users. This function acknowledges that logged-in users may minimize the IDRAK window to work in parallel with other applications.

The social proxy is a graphical social navigation approach that includes two cues, one "active" and another "passive." Passive cues can be pulled by the user when she is doing a search, whereas active cues automatically notify the user (Tollmar et al. 1996). The active cue depicts logged-in users as movable, semi-transparent colored, people-like icons. The icon turns opaque and graphically propagates a sound wave whenever a logged-in user types in the IDRAK window, but stays semitransparent and static if a user is logged-in but working on another desktop application. Further, the icon moves gradually to the foreground and its size expands when a logged-in user is actively typing in IDRAK, and conversely, it moves to the background and shrinks once a user stops typing. The passive cue enables users to make others aware of their availability 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 functional 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 (e.g., experience, interests, and capabilities). At the registration act, the user graphically plots herself into one or more communities in the knowledge map. The geometric position of the dot conveys information

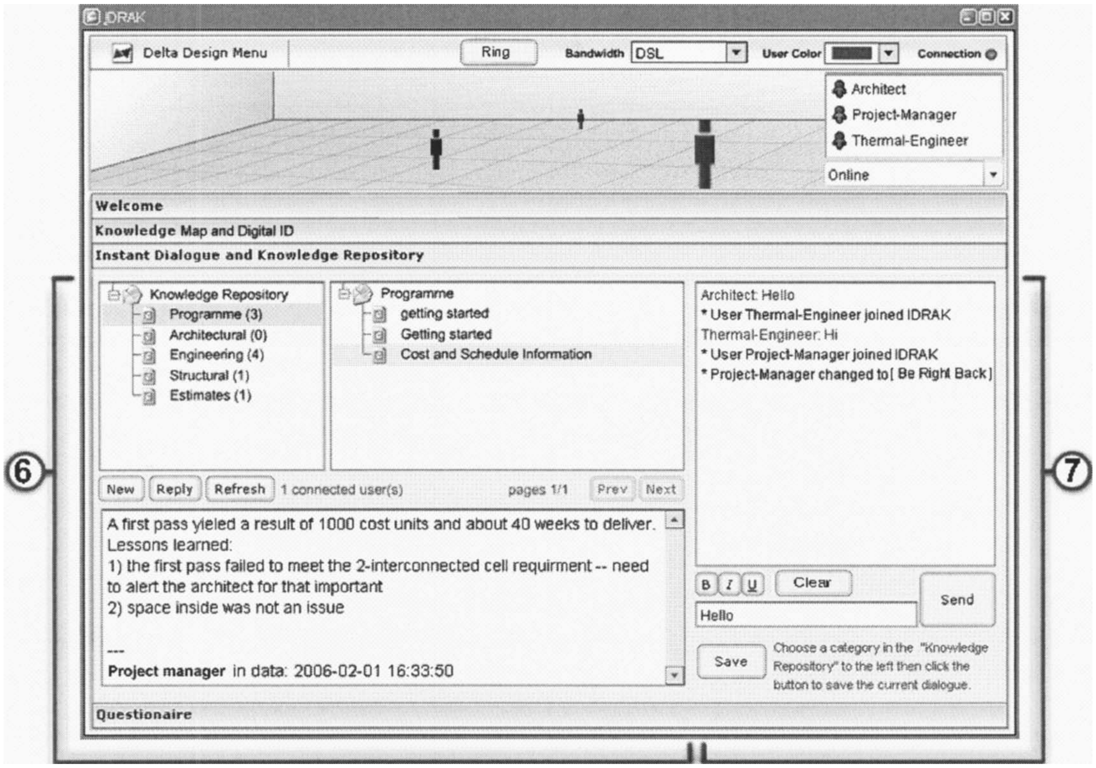

Fig. 3. IDRAK's user interface showing: (6) knowledge repository and (7) instant dialogue

about the extent a user feels she belongs (or not) to each community. For example, a user can inform others about the specificity of her know-how by plotting herself outside the area where communities overlap. Users can find out the position of registered users by dragging a "radar square" over the knowledge map—IDRAK 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 to engage in synchronous and asynchronous conversations (Fig. 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 automatically generates notifications when new users log in or out, as well as when a user changes her availability status. The "save" button in the instant dialogue box enables users to document all or part of a dialogue into the repository. IDRAK deletes automatically the conversation record from the dialogue box after the last user has logged out. Yet, it does so after a preset delay to give 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. This feature also safeguards against an unexpected loss of connectivity.

The knowledge repository enables users to examine documented conversations and engage in asynchronous conversations. The save button in the dialogue is disabled by default to disallow users from documenting a (part of) conversation without categorizing it first according to a preset ontology. We discuss later in the paper the AEC ontology that we implemented to evaluate IDRAK. A Windows-type file explorer enables users to browse and retrieve documented conversations. The repository also provides users with a box to type text. Thus, any user can asynchronously add observations to conversations documented in the repository. The "new" and "reply" buttons in the repository only get active, however, after the user applies the ontology rules to select where to archive the contribution.

Evaluating the Usability of IDRAK

Methods

We evaluated the usability of IDRAK to promote digital socialization and enhance collaborative work in a laboratory environment in the face of the difficulties to evaluate IDRAK in a real-world environment. Usability here means "the satisfaction, efficiency, and effectiveness with which specified users can achieve goals in particular environments" (ISO 1998). Our host at Arup, one of the industrial sponsors of the research, was reluctant to champion any initiative to plug IDRAK into Arup People, the in-house knowledge sharing Intranet. Key concerns related with security issues and with the time such a process would consume.

Specifically, we evaluated IDRAK by instantiating it to support the board-based Delta Design exercise. This exercise—developed by Louis Bucciarelli, a professor of design theory at MIT—has long been recognized as one of the most reliable abstractions of the engineering design process. Throughout the exercise, four individuals (playing the roles of architect, structural engineer, thermal engineer, and project manager) must develop a two-dimensional design concept for a building suitable for, and attractive to, the inhabitants of the imaginary Deltoid planet (Bucciarelli 1994, 1999). Players must place triangular red and blue tiles (termed "deltas") on a diamond-shaped grid, and check the design against the brief.

A generic brief describes the jobs of the four players and common goals, whereas four distinct technical briefs spell out the design requirements specific to each role. For example, the two

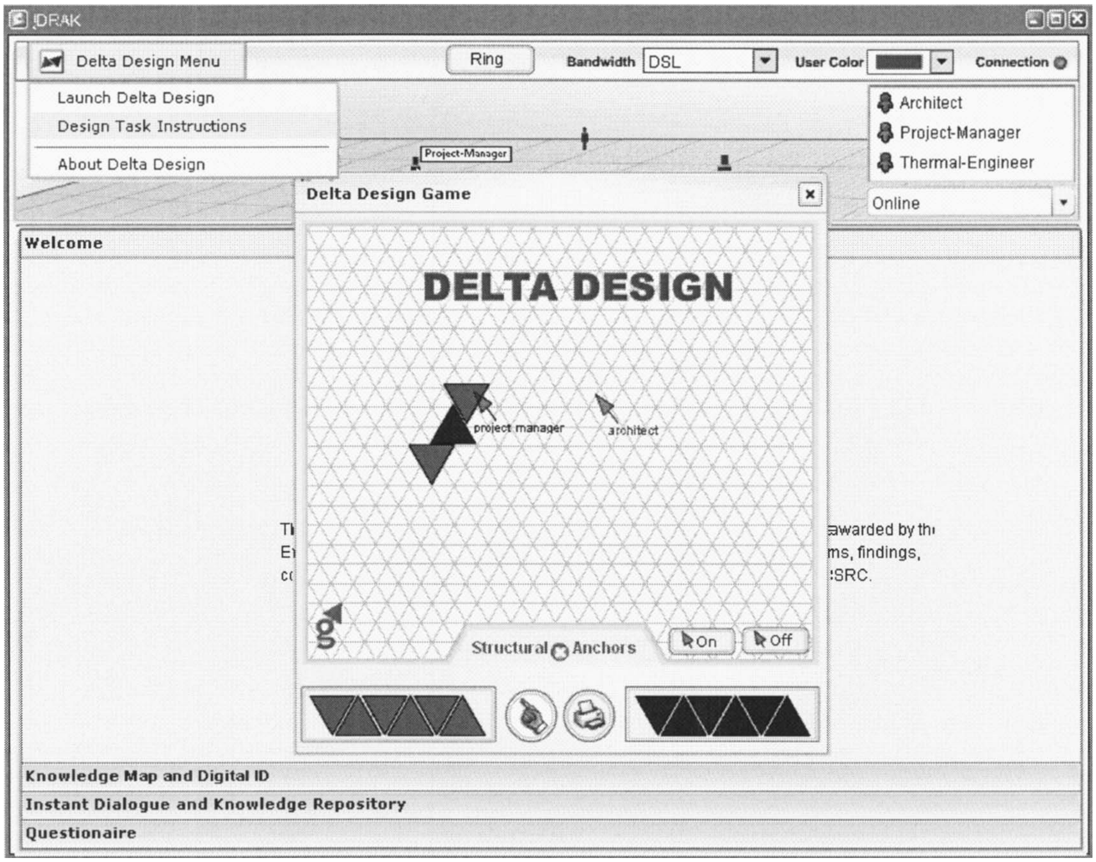

Fig. 4. Instantiation of the Delta Design window in IDRAK

engineers are provided formulas to engineer structurally stable (e.g., is there enough cement holding together adjacent tiles to cope with gravitational loading?) and thermally efficient designs (e.g., is there a balance between red and blue tiles as reds are heat sources and blues are passive?). The project manager needs to ensure that the design meets the client needs and reduces fabrication and construction costs, as well as time-to-build (e.g., the cost of the tiles varies by color and quantity purchased). And the architect is interested to meet aesthetic criteria and the client's requirements in terms of space (Bucciarelli 1994). A premise underscoring this exercise is that engineering design is a social process. As put in the Delta Design Instructor's guide:

> The exercise replicates in microcosm the sometimes uncomfortable reality that no matter how hard designers on a team try to work independently, to decompose a task into separate phases, or to define clean interfaces, they still find it impossible to avoid the intersection of interests, the framing of trade-offs, and the compromising of requirements, specifications, and goals.

Our evaluation strategy assumed that a project team could not generate a satisfactory solution unless participants shared their know-how about the Delta microcosm. This know-how is specific to the design requirements that apply in the imaginary Deltoid planet. General knowledge that an engineer or an architect may acquire through education and practice is inadequate to resolve the Delta Design problem (Bucciarelli 1994). Rather, participants needed to develop tacit knowledge by "internalizing" (Nonaka et al. 2000) the knowledge codified in the generic and technical briefs that they received a few days before the exercise. We handled the issue of reliability by ensuring that all experiments

Table 3. Dependent Variables for Evaluating Usability and Data Collection Methods [Adapted from Lewis (2002) and Hornbæk (2006)]

Usability dimensions	Definition (ISO 1998)	Dependent variables (adapted from Hornbæk 2006)	Data collection methods
Satisfaction	Freedom from discomfort, and positive attitudes towards the user of the product	System usefulness, information quality, interface quality	Standard PSSUQ questionnaire; interviews
Efficiency	Resources expended in relation to the accuracy and completeness with which users achieve specified goals	Usage patterns to solve tasks, resources expended in communication efforts	Interviews, analysis of conversational data
Effectiveness	Accuracy and completeness with which users achieve specified goals	Degree of task completion, quality of the interaction outcome	Interviews, percentage of design criteria met

Raj:	Joyce I can't see ur hand	**IDRAK Related**
Joyce:	We'd better try to move blue ones [triangular building blocks] attached to blue ones	**Work Talk**
Fiona:	Hang on you guys! Your moving too fast for me!	**Work Coordination**
Raj:	Temperature should not go below 20 Nn	**Work Talk**
Fiona:	We haven't set the centre of gravity yet! The Building's no good if it won't stay up!	

Fig. 5. Example of content coding on a fragment of a conversation (Joyce is project manager; Raj is thermal engineer; and Fiona is structural engineer)

unfolded under the same set of conditions. First, we disallowed participants from socializing through face-to-face and phone conversations ex-ante of the exercise. Second, we sat team participants away from each other to force socialization through IDRAK during the exercise.

We complemented IDRAK's capabilities by providing a digital board where users could simultaneously pick and move the tiles on a diamond-shaped grid (see Fig. 4). Further, we instantiated IDRAK with a subset of the e-COGNOS ontology—an ontology on the semantics underscoring the content and interdependencies of documents used in AEC projects to promote consistent knowledge management within collaborative environments (Zarli et al. 2000). e-COGNOS comprises a set of models, including main user profiles (e.g., project manager, architect), class diagrams to describe design tasks (e.g., site analysis, sketch design, programming), and relationships between tasks and outputs.

Four test runs were undertaken in a cluster of desktop PCs with graduate students enrolled in a program in operations management. The language of the exercise was English, but students came from at least seven different countries. Students were allowed 90 min to develop and "negotiate" (Bucciarelli 1994a) a design concept. We summarize in Table 3 how we collected the data needed to evaluate the standard dimensions of usability (Hornbæk 2006).

Findings

We evaluated satisfaction through the standard PSSUQ questionnaire (Lewis 2002). We requested users to complete it online at the end of each test run, and cross checked the results against interview data. The questionnaire assesses three dependent variables, each of which being an aggregate construct based on the average response to an independent set of statements. Satisfaction, in turn, is an aggregate construct of the three dependent variables (results summarized in the Appendix). The results yielded positive ratings for the three dependent variables and a positive "overall satisfaction" rating of 3.09. In the words of a player queried about the extent she was satisfied with the system: "In the beginning it requires some attention but as you go on, it [using IDRAK] gets better and better." Considering that users only got a 15-min introduction to using IDRAK, the positive rating suggests that IDRAK was easy to use.

We received, however, some suggestions to improve satisfaction. On one hand, some users suggested complementing the social proxy with audio awareness cues; as put by a user: "It is sometimes easy to miss people talking while you are working on other things; it would be helpful for messages arriving on the dialogue to be accompanied by some kind of noise." CSCW recommends, however, prudence in providing audio-awareness cues because of the level of user annoyance that accompanies them (Isaacs et al. 2002). On the other hand, some users expressed interest in using audio alongside the chat-based communication: "It will be easier if members can talk to each other . . . [and] not only type stuff [in]." We chose the less intrusive text-based medium because it allows multitasking, requires little effort to initiate and retrieve messages, offers minimal message transfer

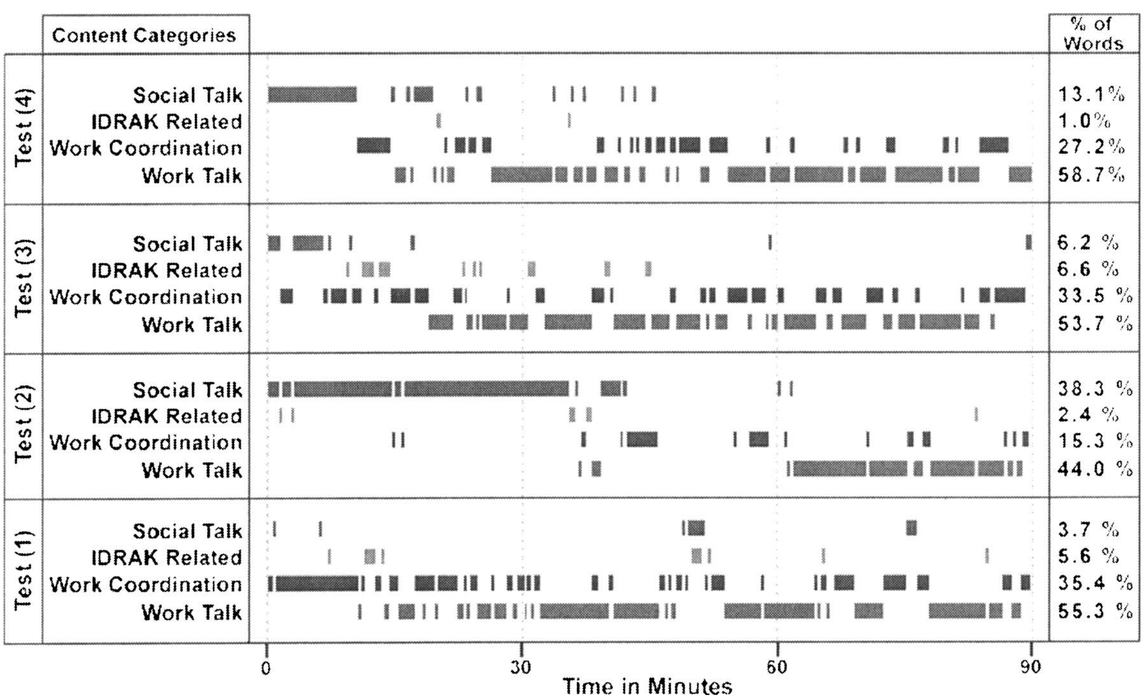

Fig. 6. Progression of content coding throughout the test runs

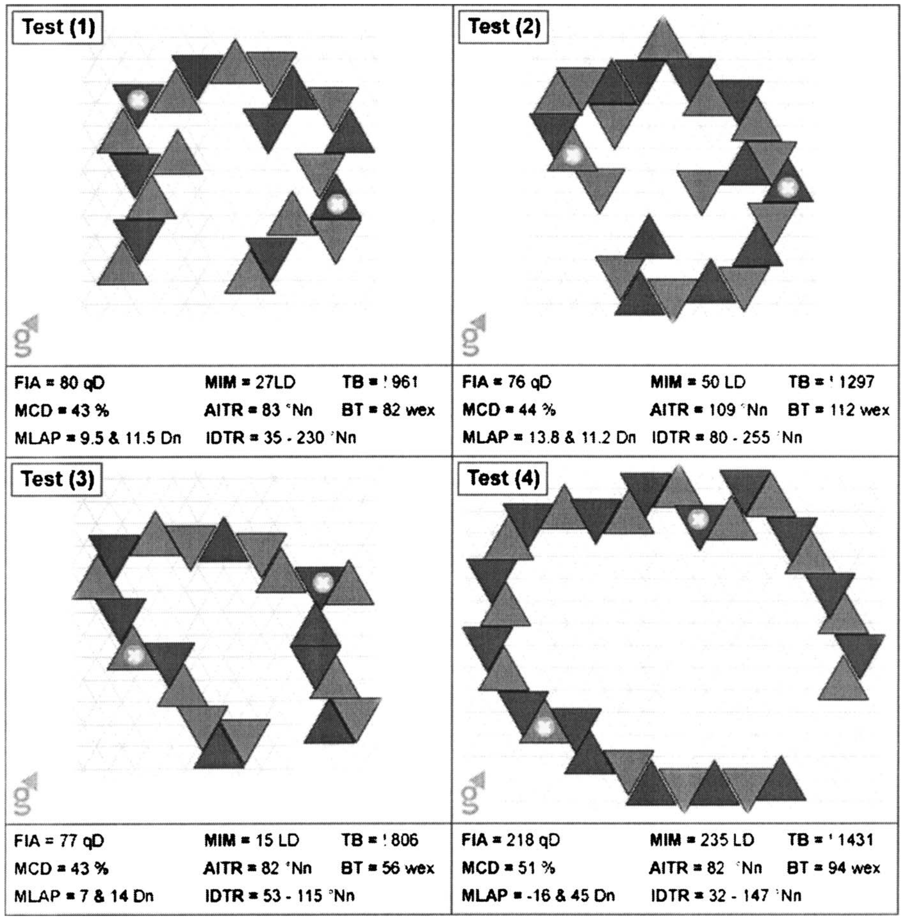

Fig. 7. Analysis of the design quality of the digital exercise outcomes

time with a standard information technology (IT) infrastructure, and has the ability to persist across time and space (Nardi et al. 2000; Isaacs et al. 2002). Yet, we agree that integrating voice/video with chat can create more effective "parallel channels" in line with the Isaacs et al.'s (2002) vision of the day of when affordable high-bandwidth infrastructure and technology developments will make pervasive video- and audio-based interactions.

To learn about IDRAK's efficiency, we recorded a total of 951 conversational turns with a total of 9,095 words, which averages 9.56 words per turn. The brevity of the conversations is in line

Table 4. Descriptive Statistics of Outcomes for Board and Digital Design Exercises

			Standardized distance to threshold $Z_i = X_i - \text{threshold\_of\_}X_i / \text{Std\_dev\_}(X_i)$			
			28 runs; board exercise		4 runs; digital exercise	
	Design criteria	Design threshold	μ (Z_i)	σ (Z_i)	μ (Z_i)	σ (Z_i)
Architectural	(1) Functional internal area (FIA)	⩾100 qD	0.49	1.00	0.18	1.00
	(2) Maximum blue deltas (% total) (MCD)[a]	⩽60–70%	−1.92	1.00	−6.41	1.00
Mechanical	(3.1) Average internal temperature range (AITR)	⩾55° Nn	0.54	1.00	2.55	1.00
	(3.2) Average internal temperature range (AITR)	⩽65° Nn	−0.51	1.00	1.80	1.00
	(4.1) Minimum individual delta temperature range (min IDTR)	⩾20° Nn	1.02	0.96	1.36	1.00
	(4.2) Maximum individual delta temperature range (max IDTR)	⩽85° Nn	0.83	0.64	1.53	1.00
Structural	(5) Maximum load at anchor points (MLAP)	⩽20 Dn	1.28	1.00	0.07	1.00
	(6) Maximum internal moment (MIM)	⩽40 LD	1.11	0.71	0.40	1.00
Project manager	(7) Total budget (TB)	⩽1,400	0.61	0.90	−0.95	1.00
	(8) Building time (BT)[b]	Shortest	76.15	41.53	86.00	23.49

[a]Standardized in relation to the upper threshold (70%).

[b]Not standardized as a threshold was not provided.

with previous research on the length of informal interactions in the workplace (Isaacs et al. 2002; Halverson et al. 2003). We also coded and analyzed the recorded conversational data using the following set of coding schemes developed to evaluate research on instant messaging and persistent chat prototypes (Isaacs et al. 2002; Nardi et al. 2000; Halverson et al. 2003): (1) *work talk* includes conversation turns focused on problem-solving, e.g., quick question and answer pairs; (2) *work coordination* includes conversation turns needed to coordinate tasks; (3) *Social talk* includes greetings, goodbyes, weather issues, humor, and personal remarks; and (4) *IDRAK related* includes conversation turns about issues related with the use of the tool. Fig. 5 illustrates the administration of content coding criteria on a sample of a recorded conversation, and Fig. 6 shows how the dialogues progressed throughout each test run.

Test Runs 1, 3, and 4 replicated a usage pattern that manifests a predominance of "work talk" and "work coordination," measured by total number of words. This finding lessens hypothetical concerns that IDRAK would lend itself to support a disproportional amount of time in "social talk" at the expense of work-related activities. Further, the low percentage of the "IDRAK related" category suggests users encountered few technical problems, corroborating the positive rating in terms of users' satisfaction. The exception to this pattern was the Test Run 2 in which a technical glitch precluded the "architect" to log in for approximately the first 30 min. As the other three players waited for the IT administrator to sort out the problem, they used IDRAK to talk about holiday destinations, leisure activities, and weather, thereby using IDRAK to support informal social interactions and building of social bonding.

The effectiveness of IDRAK was the most difficult dimension to evaluate because we only had an incomplete set of data about the outcomes of the board exercise to compare against our limited data about the outcomes of the experiments. Hence, our findings are only indicative of the extent the digital outcomes met the criteria spelled out in the design briefs (summarized in Fig. 7 and Table 4). We understood from the outset that it would be unlikely that teams of graduates could reach optimal solutions in 90 min (Bucciarelli 1994a), or even solutions that would "satisfice" (Simon 1969) all design criteria. This was corroborated by the unpublished results accomplished by 28 different groups of engineering graduates and MBA students who spent 90 min playing the board exercise (S. Beckman and A. Agogino, private communication, 2002). (This data set was incomplete as it missed some results of the architectural characteristics of each solution.)

A comparative analysis of the descriptive statistics on the standardized distances to the thresholds for each design criterion suggests the following: (1) both digital and board exercise performances met the key architectural criteria; (2) the digital exercise performed poorer than the board exercise from a mechanical perspective; (3) it performed better than the board exercise from a structural perspective; and (4) the digital solutions would cost less, but take more time to build. While these results do not have any statistical significance, they allow conjecturing that the performance accomplished by the virtual teams may not be far off from the performance accomplished by the teams who got physically together to play the exercise.

From a structural design perspective, only the outcome of Run Test 4 failed to meet the brief, with one anchor point subjected to loads more than double the design limit. This solution would require a radical redesign. From a mechanical design perspective, the four solutions would require rework to meet the brief—this is not surprising as the "mechanical engineer" needs to make laborious calculations to check the design against the brief. From an architectural perspective, the four solutions met the criterion that limits the number of blue triangles, but only Runs 1 and 2 met two additional architectural criteria: provide an entrance aligned with the gravitational force and a sense of two interior areas. An aggregate construct that expresses the number of criteria met in each test indicates that Run 1 met 6 criteria out of 10, whereas Run 4 performed extremely poorly, and the performance of Runs 2 and 3 was moderate.

As we play the product design results against the process data, we generate some questions that merit further research. For example, we can notice that players in Test Run 1 spent the initial 30 min coordinating the work before starting design development (e.g., how do we agree when to make changes versus hold on to make calculations; what do you know that I need to know and vice-versa). In contrast, Teams 3 and 4 repeatedly switched between conversations focused on work coordination and problem-solving issues and Team 2 hardly discussed work coordination issues. This finding corroborates theory on how different users appropriate digital tools in distinct ways (Orlikowski 2000). We conjecture, however, that failure to agree rules upfront about how to best use, and avoid misuse of, IDRAK can undermine its effectiveness.

Conclusions

This research contributes a prototype of new digital media to promote socialization in "virtual" AEC project teams. This framework pieces together key CSCW features, including synchronous text chatting and recording, social proxy, and knowledge map. Admittedly, the rapid development of new audio/video digital systems in the real world, such as MSN Messenger, Office Groove, and Skype, has outpaced the originality of some IDRAK features. Thus, we believe the main contribution of this research lies in engineering a novel methodology to evaluate the usability of digital prototypes to support virtual engineering design teams.

Yet, we should not lose sight of the limitations of experiments. Reality is much more complex than our lab setting. Projects invariably involve more than four participants. Decision-making involves many more intricate variables and problems; and the Delta exercise only mimics the early project design stage. Thus, it is worthwhile developing new evaluation methods that can provide insights on the usability of digital prototypes after these get scaled up to support real-world project environments. It also merits further research which rules need to be developed to help teams make the most effective use of tools to support digital socialization.

Finally, IDRAK helps users to build a repository of knowledge that complements the synchronous context-rich, but the usability of this feature remains indeterminate because we ran our tests in parallel. Recent research suggests that there are benefits to project performance stemming from broadening the accessibility to documented conversations through intelligent searches (e.g., Zaychik and Regli 2003; Fruchter and Luth 2004). Research also suggests that the implementation of explicit reputation mechanisms, similar to those found in online auction websites, works as an incentive for people to spend time building knowledge repositories and retrieving knowledge (Jensen et al. 2002). We plan to further develop IDRAK and perform more test runs in the future to learn more about how digital socialization can enhance asynchronous collaborative work in the world of AEC projects.

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Appendix

Descriptive Statistics of the Standard PSSUQ Questionnaire (7-Point Likert Scale (1=Strongly Agreee; 7=Strongly Disagree)

Question	Mean	Standard deviation	Median
1. Overall, I am satisfied with how easy it is to use this system.	2.75	0.86	2.50
2. It was simple to use this system	2.50	0.79	2.50
3. I could effectively complete the tasks and scenarios using this system.	3.33	1.30	3.00
4. I was able to complete the tasks and scenarios quickly using this system.	3.58	1.31	3.50
5. I was able to efficiently complete the tasks and scenarios using this system.	3.41	0.90	3.50
6. I felt comfortable using this system.	2.58	0.79	3.00
7. It was easy to learn to use this system.	2.83	1.64	2.50
8. I believe I could become productive quickly using this system.	3.08	0.90	3.00
System usefulness (average 1–8)	**3.01**	**0.56**	**3.00**
9. The system gave error messages that clearly told me how to fix problems.	4.66	1.30	5.00
10. Whenever I made a mistake using the system, I could recover easily and quickly.	4.00	1.53	3.50
11. The information (such as on-line help, on-screen messages and other documentation) provided with this system was clear.	3.25	1.35	3.00
12. It was easy to find the information I needed.	3.16	1.26	3.00
13. The information provided for the system was easy to understand.	2.66	0.98	3.00
14. The information was effective in helping me complete the tasks and scenarios.	3.25	1.91	4.00
15. The organization of information on the system screens was clear.	2.91	1.16	3.00
Information quality (average 9–15)	**3.41**	**0.99**	**3.35**
16. The interface of this system was pleasant.	2.16	1.74	2.00
17. I liked using the interface of this system.	2.41	1.50	2.00
18. This system has all the functions and capabilities I expect it to have.	3.58	0.99	3.00
19. Overall, I am satisfied with this system.	2.66	0.65	3.00
Interface quality (average 16–19)	**2.70**	**0.85**	**2.50**
Overall satisfaction (average 1–19)	**3.09**	**0.66**	**3.05**

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