CAN KNOW-HOW BE SIGNALED?

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ABSTRACT

Knowledge here is defined as applying to the body of facts gathered by study, observation, and experience, as well as to the ideas inferred from those facts. Knowledge connotes an understanding of what is known. Whereas explicit knowledge has been formalized and codified, tacit knowledge may exist only in the heads of individuals. Know-how here means a subset of tacit knowledge, comprised of its operational and logistic dimensions. First, this paper articulates the problem of the lack of transference of tacit knowledge between designers and builders. It questions to what extent means and methods can be developed to help individuals signal some degree of tacit knowledge, and thereby enhance the subsequent transfer of know-how across architecture-engineering-construction (AEC) organizations' boundaries. Then, a literature review of knowledge engineering and management as applied to the AEC domain is presented. Finally, the objectives and the expected results of a proposal to investigate hypothetical ways to help designers and builders signal their know-how are discussed.

KEY WORDS

Knowledge management, communication, tacit knowledge

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INTRODUCTION

Up to the industrial revolution, master builders, such as Vitruvius or Sir Christopher Wren, gathered in their heads a breadth of knowledge and experience on the diverse disciplines involved in design and in construction. Large construction projects would then last for decades if not centuries. In the course of time, the complexity of architecture-engineering-construction (AEC) product development processes has increased significantly. Available technologies, equipment, and materials have expanded in number and in diversity. The pressure exerted by clients for compressing project delivery times has also increased. Specialists replaced generalists. Information on AEC products and processes has dispersed across different disciplines (Alexander 1964), and within each discipline across specialized designers, contractors, and suppliers of equipment and materials.

Information is different from knowledge. Information is data that has been gathered in some way, such as in databases, drawings, and specifications, but it does not necessarily connote validity. Knowledge is defined as applying to the body of facts gathered by study, observation, experience, as well as to the ideas inferred from those facts, and connotes an understanding of what is known (Websters 1997). It is also important to distinguish explicit from tacit knowledge. Whereas the former is knowledge that has been formalized, the latter is knowledge that has not necessarily been codified but may rather exist only in the heads of individuals. An example of tacit knowledge is the understanding of proper trade sequences for construction operations gained through experience by trades' people. Know-how here means the subset of tacit knowledge comprised of its operational and logistic dimensions.

AEC practitioners in different firms share knowledge along design and construction development processes. If technologies, such as e-mail and Internet, support transfer of codified knowledge, they still have a limited ability for signaling and transfer tacit knowledge. Also, recent computational environments developed to support collaboration between design and construction firms seldom explicitly address the problem of the way these tools can help designers and builders to transfer know-how between them (e.g., P3 in Kalay (1998), 4D CAD in Koo and Fisher (2000)). Sharing of tacit knowledge remains essentially, both in theory and in practice, an informal process, limited to face to face meetings, and phone/video talks. Indeed, the value of personal interaction has merited the attention of partnering initiatives (e.g., Matthews et al. 1996). However, if tacit knowledge transfer exclusively relies on erratic conversations, the risks are high that these may occur too late along development, or worse, may not occur at all.

This paper is organized as follows: After articulating the problem of tacit knowledge transfer between designers and builders, a literature review of knowledge engineering and management as applied to the AEC domain is presented. Then, the objectives and the expected results of a proposal to investigate hypothetical ways to help designers and builders signal know-how and thereby enhance knowledge transfer between these practitioners are discussed.

THE PROBLEM

AEC products are increasingly more complex. Projects typically involve a myriad of designers, contracting specialists, and suppliers of equipment and materials. Throughout design and construction development, these professionals must continuously share both explicit and tacit knowledge within and across AEC organizations' boundaries. Explicit knowledge has been codified in some way, such as in drawings, specifications, databases, or catalogues of parts. As a result, explicit knowledge is relatively easy to transfer between designers and builders. Sharing of codified knowledge occurs, for example, when designers consult catalogues of parts published by suppliers or when they evaluate bidding documents produced by contractors, or when contractors and suppliers (the builders) study drawings and specifications produced by designers. Depending on the project delivery system, transfer of explicit knowledge between designers and builders can happen earlier or later along project development, and can be more or less effective. Occasionally, exchange of explicit knowledge continues along the life cycle of the AEC product, for example, for solving operational and maintenance issues.

In contrast, tacit knowledge has not necessarily been either codified or divulged by those to whom it belongs. Individuals acquire tacit knowledge by experience, by going through similar tasks repeatedly, by sharing stories (Orr 1996), or, paraphrasing Polany (1966), by dwelling in things. Because tacit knowledge belongs to individuals, firms must create incentives to motivate them to share it with others within their organizations and, even more challenging, across organizational boundaries.

Based on evidence I collected from prior empirical research (Gil 2001) and from recent interviews with AEC practitioners, I assert the following: A substantial share of designers- and builders' knowledge beyond what they formally share between them remains tacit. Unless individuals meet face to face or talk on the phone/video, they have enormous difficulties in sharing know-how.

Yet to presume that project organizations would always set in place the necessary conditions for designers and builders to meet at the right time is unrealistic. If know-how is not properly signaled it may happen, first, that it takes a long time before individuals discover its availability, and worse, know-how may never get transferred because individuals remain unaware of its existence throughout product development. Ignorance of available know-how leaves designers and builders with less guidance to make informed decisions, to interpret available information, and to handle information overload. Operational ignorance makes it harder for designers to spot the right questions, and to identify those in builders' organizations to whom questions should be asked. Likewise, if builders ignore the reasons that may underline specific project decisions made by designers, builders will be less able to judge decisions correctly, or to propose alternative solutions that could work better. In addition, inadequate understanding of problems hampers individuals from setting objective purposes for meetings, and from contributing to make meetings more productive.

In contrast, if builders can successfully signal know-how to designers, the latter can be guided on which operational and logistic questions they should ask, to whom questions should be asked, and when questions should be asked. Builders can also elucidate designers on the field implications of alternative design decisions and production choices. Vice versa, if designers signal their know-how to builders, the latter can provide designers with more objective feedback on design decisions. Signaling know-how increases chances for timely knowledge transfer along design and construction development. As designers and builders share know-how, they will better understand what they know and what they do not know, and will have opportunities to learn new things, or in other words, to increase their own knowledge. As the knowledge possessed by each individual increases, that individual can more easily come up with innovative ideas for current problems in design and in construction, creating new knowledge. This new knowledge can then be formalized to be made accessible to others in the organizations and thereby to create more knowledge, a process Nonaka (1991) called the spiral of knowledge creation.

Still, in practice, transference of tacit knowledge is a complex problem. Individuals are proud of what they know and who they know, and do not like to spread knowledge within and across firm's boundaries unless they can expect some kind of rewards for doing it. Firms also care to protect trade secrets. For an outsider to a firm, to learn who knows what in that firm can be difficult because subsets of knowledge are not necessarily concentrated in individuals but rather may be scattered across different individuals, in what Brown and Duguid (1991) called communities-of-practice. In addition, even when outsiders are aware of available know-how, it does not necessarily mean they have the required experience or understanding to absorb it, a difficulty expressed by the concept of absorptive capacity (Cohen and Levinthal 1990). For example, tacit knowledge may only be meaningful if embedded in a practical context, which makes it hard to retrieve by people who do not have some level of practical experience.

Some procurement strategies used by clients also do not promote knowledge transfer between designers and builders. In particular, in the design-bid-build system-in which contractors and suppliers get selected only after the design has been substantially developed by a design firm-few incentives and opportunities exist to promote know-how transfer (Pietroforte 1997). However, in alternative procurement strategies, such as the design-build system-in which the client contracts from the start with an organization that brings together design and building firms-more opportunities exist (and the organization can more easily set up incentives) to promote collaboration between designers and builders. Regrettably, industry research has revealed results that are often inconsistent with one another regarding to what extent the willingness of clients to adopt the design-build strategy is or is not increasing (e.g., contrast Songer and Molenaar 1996; Rowings et al. 2000 and Greenwood 2001).

LITERATURE REVIEW

KNOWLEDGE ENGINEERING AND MANAGEMENT

In the domain of knowledge engineering and management as applied to the AEC industry, researchers have been undertaking a significant effort to develop systems - complementary to personal interaction - for enhancing explicit and tacit knowledge transfer. For example, knowledge- and expert-based systems capture and encapsulate knowledge specific to particular problems or tasks in computer systems, so non-experts can tackle similar problems by using the systems (e.g., Hendrickson et al. 1987; Odeh 1992). The limited success of these systems in practice has been largely attributed to their high costs of development and maintenance, and to the abrupt decline of their ability to support problem-solving outside the boundaries of their expertise domain (e.g., Verkasalo and Lappalainen 1998, McDermott 1999).

Recent research propositions have explored information technologies for leveraging the capabilities of expert systems. For example: Tumkor (2000) embodies a web-based expert system in on-line part catalogues; Rodgers et al. (1999) describe WebCADET, a reimplementation of a knowledge-based system via web for facilitating communication of design knowledge between designers; and Anumba et al.'s (2002) ADLIB project uses distributed AI theory to integrate a self-contained knowledge-based system with a negotiation mechanism based on game theory. Still, the capabilities of these systems remain largely constrained by the limitations of expert systems even if the web makes them more easily accessible. The extent to which wider accessibility can turn these systems into commercially viable propositions remains an open question. With less ambitious goals, Coyne et al. (2001) propose PLA(id), a web-based product library assistant for organizing product knowledge that is currently posted on the web. PLA(id) does not deal, however, with tacit knowledge.

Other computational environments have integrated knowledge of design and construction operations for helping users better solve design and scheduling problems, frequently borrowing concepts from the field of Artificial Intelligence. For example, Dzeng and Tommelein (1997) developed the CasePlan system to facilitate schedule reuse adopting case-based reasoning, a problem-solving method that implements a set of past cases plus mechanisms for retrieving cases and adapting their solutions to suit new problems. Lottaz et al. (1999) developed a system that codifies and embodies decision rules used by practitioners and exhibits simulation capabilities for helping practitioners judge design alternatives from an operational perspective. Yet, although these prototypes have been successfully validated from a theoretical standpoint in restricted field settings, it is hard to predict if the concepts will ever make it into real world practice. It remains unclear to what extent the prototypes are scalable to support the larger and more complex design and planning problems of real-world projects. Whether the systems would be commercially feasible after being scalable is an open research question. The fact is these systems would require continuous updates to stay aligned with available technologies, equipment, materials, and skills, and thereby avoid obsolescence.

More recent developments in knowledge engineering and management have explored information and communication technologies. British Petroleum (BP) is frequently mentioned for the 'smart' use of information technologies for networking employees and for replicating employee's knowledge throughout the company (e.g., Prokesch 1997). Regrettably, to the best of my knowledge, literature available on BP practices is vague on the specifics of the systems implemented.

Knowledge discovery in databases (KDD) and data mining (DM) are other research areas in knowledge engineering whose applicability to the AEC industry has started to be recently explored (Soibelman and Kim 2002). These techniques aim, first, to automatically assist humans in analyzing the volumes of data generated by computer technologies, and second, to help managers develop a better understanding of causal relationships that may explain predictable patterns to be found in the data. Conceptually, this work is very distant from the work being proposed here. Whereas KDD and DM as applied to the AEC industry use data as input for reactively extracting lessons (or knowledge) to be applied in future projects, signaling tacit knowledge aims to proactively elicit knowledge to avoid construction problems before they occur.

Some work in the production and lean management domain can also be interpreted from a knowledge management perspective. Having the know-how of production people accessible from the onset of design development is fundamental to operationally implement lean management principles. Collaboration of production people in design brings several benefits: (1) allows information and know-how sharing, which helps to reduce uncertainty in the development process and to align design with production capabilities; (2) contributes to make the production process more flexible to adapt late design changes; (3) helps to streamline production supply chains; and (4) promotes innovation in product design (e.g., Womack et al. 1990, Iansiti 1995, Sabbagh 1996).

To enhance knowledge transfer, lean literature advocates face to face interaction, by means of co-location, job rotation, and cross-functional teams. Collaboration between designers and builders from the onset of design development is also a fundamental principle in lean construction theory (Tommelein and Ballard 1997). Collaboration allows for effective and timely communication, which helps individuals to make informed decisions, to develop better understanding of project uncertainties, and to allocate risk more equitably (Higgin and Jessop 1965). Collaboration between designers and builders is also valuable for promoting innovation in the industry (Slaughter 1993). Knowledge transfer is crucial for successful collaborations.

Recently, Gil et al. (2001a), based on empirical research, articulated the contributions of specialty contractors' knowledge to early design in four segments: (1) to push forward innovation and creativity in AEC products and processes, (2) to convey understanding of space needs for executing construction operations, (3) to convey understanding of fabrication and construction capabilities for supporting choices between design alternatives, and (4) to provide better sense for suppliers' true lead times and reliability. Examples of methods that organizations have implemented to facilitate know-how transfer are co-locate people who work for design firms with people who work for contracting firms, establish long-term relationships between firms, and empower individuals in client organizations to ensure an effective liaison between designers and builders (Gil et al. 2001a). Other methods, common in manufacturing but less in the AEC industry, consist of rotating engineers across design and production jobs, creating cross-functional teams, and allowing assembly engineers to reside in suppliers' facilities for limited periods of time, the so-called guest engineers (e.g., Clark and Fujimoto 1991).

Recent tools developed by researchers to support project management are harder to interpret from a knowledge engineering and management perspective. For example, Koo and Fischer's 4D CAD (2000) links tri-dimensional visualization capabilities of a product model with an activity-based network. 4D CAD aims to help project teams anticipate construction problems, such as possible space conflicts of crews, safety issues, and site workspace restrictions, so construction work can be re-planned accordingly. Yet, the literature is unclear on the way 4D CAD is being used: whether as a tool for embedding suppliers and contractors' know-how in the early design effort, or as a tool for getting more objective builders' comments on a design previously developed by designers. Leveraging the world wide web, Kalay (1998) proposes P3, a collaborative design environment to facilitate sharing of project information across a community of designers. P3 supports exchange of explicit design knowledge, apparently excluding builders and suppliers from the virtual network. As with 4D CAD, it is not obvious how P3 addresses the problem of transferring tacit knowledge. Tacit knowledge could help designers to more rapidly identify and retrieve important information made accessible by P3, and to better prioritize design tasks.

Closer to the goal of this research is Numata and Taura's (1996) proposal of a symbiotic network for sharing and amplifying tacit knowledge transfer between engineers within product development organizations' boundaries. Numata and Taura envision a network that virtually integrates product simulators, process databases, and communication technologies, accessible through personal computers and workstations in a company. Signaling and transferring some dimensions of know-how not within but across organizations' boundaries is an even more challenging problem.

RESEARCH OBJECTIVES

The purpose of this research is to develop means and methods for enhancing high-competence contractors and suppliers to signal-and designers to retrieve-know-how along AEC product development. High-competence contractors and suppliers are firms with recognizable expertise in engineering and in design. The goal is to help designers be more aware of available know-how and thereby to spur timely transfer of know-how across firms' boundaries. Consideration will also be given to engineer ways to help designers signal their own tacit knowledge to builders. Figure 1 expresses this concept.

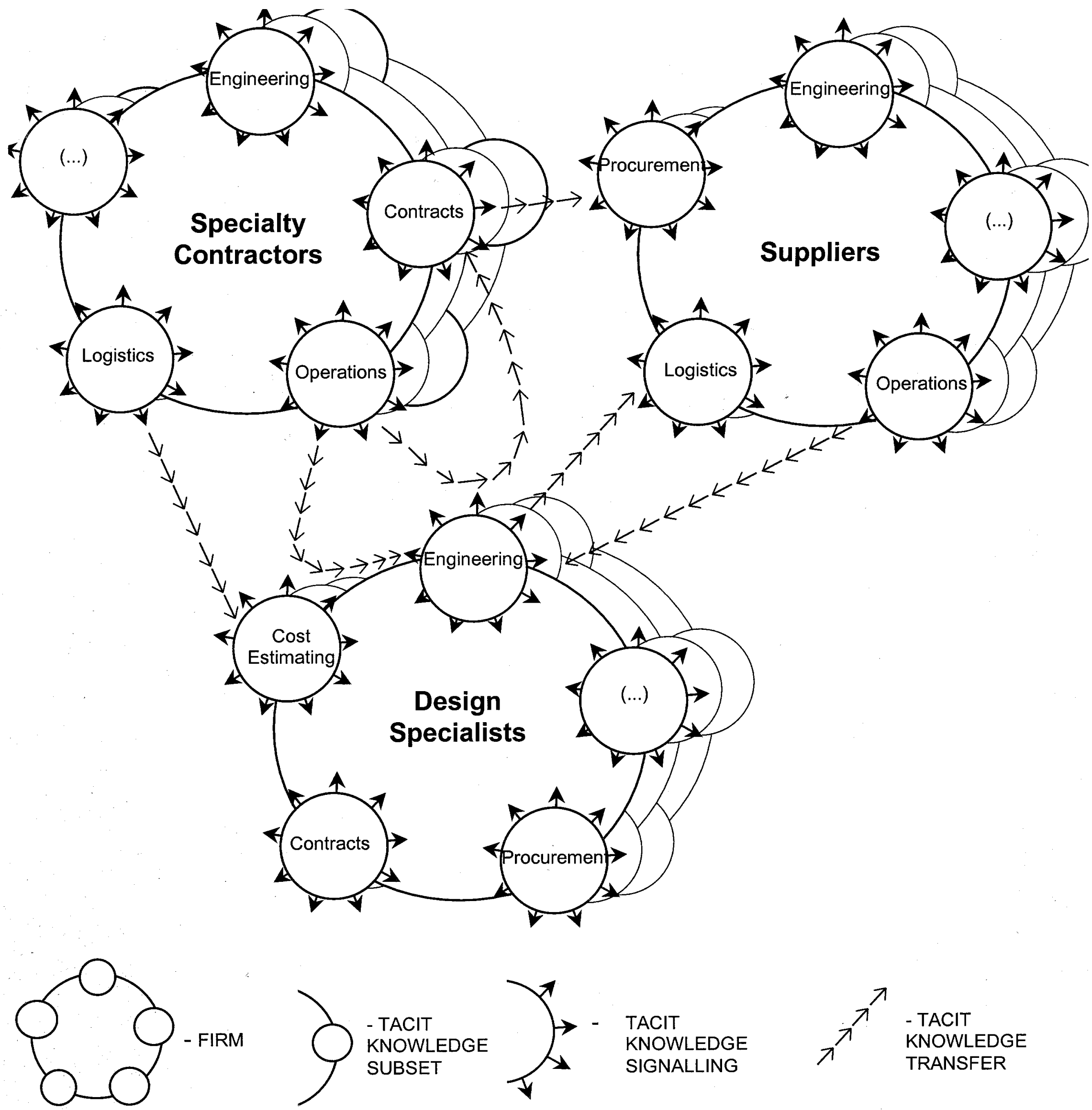

Figure 1 : Pictorial Representation of Tacit Knowledge Signaling Concept

The idea of engineering systems that signal know-how is more flexible and feasible than that of attempting to codify tacit knowledge. Flexibility to update flagged or posted know-how is important so firms can maintain the systems aligned with the fast pace of development in technologies, in materials, and in equipment, with turn-over, and with the frequent changes in available skills and products. Signaling know-how also suggests less costly means to enhance knowledge transfer across organizations' boundaries. Low development and maintenance costs increase chances that systems stay commercially viable. The research also aims to develop prototypes that in some way attempt to replicate "the more graceful decline exhibited by human experts in their ability to perform near the boundaries of their expertise" (Davis 1986). For example, a system that not only would signal individuals' know-how but also would network its users to other sources of know-how within firms, as expressed by the curly lines of arrows in Figure 1.

Systems for signaling know-how can also work as a complement of builders' efforts to market their services to designers. As such, firms would do well to invest in this kind of system regardless of the contracting practices, if they prove to be commercially viable and can protect trade secrets.

Specifically, the research objectives will comprise: (1) develop further understanding of the content of designers-, builders-, and suppliers' know-how and of the appropriate time, means, and incentives for signaling it; (2) investigate which specific dimensions of tacit knowledge can possibly be elicited and transferred along design and construction development; (3) conceptualize and develop prototypes; and (4) test the validity of these prototypes and feedback results to academic and professional communities.

AN EXAMPLE OF KNOWLEDGE SIGNALING

Individuals and firms have found different ways to signal knowledge across organizational boundaries. For example, many researchers display in their electronic signatures the address of their own web pages. These web pages typically show the bio of the researcher, the papers he or she has developed, and current research, teaching, and professional interests. In doing so, the researcher is signaling his or her knowledge to other people, both explicit knowledge (such as the papers presented in conferences or innovative software that has been developed) and tacit knowledge (such as brief statements on current research and teaching interests). Occasionally, personal web pages also guide visitors to other related web pages. In doing so, researchers contribute to create on-line communities of people with shared research interests, and thereby smooth the decline of the knowledge signaled in the web pages near the boundaries of each one expertise.

Other examples of ways practitioners signal knowledge can be found in the manufacturing and computer industries. The web site of the airplane manufacturer Boeing makes available the names and e-mail addresses of key people in the diverse departments of the organization, and it also makes explicit the knowledge domain of each one. Each individual is in charge of responding to queries received from the outside world related to his expertise. By doing so, Boeing has been implementing a way to signal who knows what in the organization to visitors of Boeing's web page and thereby enhance subsequent knowledge exchange. Likewise, the computer manufacturer Dell currently signals, to buyers of its products, the electronic mail and chat addresses of experts in different areas related with product installation and operation (by means, for example, of making this information immediately available once the product is connected to the Internet). As a result, buyers of Dell computers more easily can get support for problems they come across throughout hardware installation and operation processes.

The examples presented above illustrate means and methods implemented by individuals and by firms to signal knowledge across boundaries. These examples differ however from the research objectives here since they do not relate to signaling operational tacit knowledge between design and production people. Admittedly, this author did not come across with any satisfying example from the AEC industry. This fact may only reinforce the research opportunity that lies ahead in investigating innovative means and methods for designers and builders to effectively signal know-how.

EXPECTED RESULTS

Can know-how possessed by individuals be signaled and transferred across AEC organization's boundaries? I believe so. Future research will unveil to what extent this belief is realistic. Established theory in knowledge and production management leads to the conclusion that AEC organizations would gain if individuals could signal their know-how across organizations' boundaries. Examples from other fields show that firms and individuals have found ways to signal explicit and tacit knowledge across organizations' boundaries.

This research will be developed across two domains: (1) the information and communication technologies domain, by exploring the potentialities of World Wide Web, extranets, project-based intranets, and wireless media; (2) the physical domain, by exploring the incorporation of diverse knowledge dimensions in physical prototypes, artifacts, and product catalogues.

Future research expects, first, to sharpen understanding of the dimensions of builders' operational knowledge that may be transferable; and second, provide prototypes for enhancing know-how transfer and thereby support AEC organizations as they strive to restructure procurement practices, streamline their processes, and implement lean principles. Means and methods, complementary to personal interaction, that signal and enhance tacit knowledge transfer will extend each individuals' own tacit knowledge base, and help them to articulate and convert their knowledge into explicit knowledge. The ultimate goal of the proposed research is to provide prototypes for accelerating the speed of knowledge creation in the AEC industry, an industry commonly judged a slow innovator.

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