KNOWLEDGE, AGENCY, AND DESIGN INFORMATION SYSTEMS

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This paper addresses CAAD from an organizational point of view. We employ recent developments in organizational economics to model the organizational processes in building design. Based on an analysis of the cost of transferring knowledge, and (ii) agency cost in existing design organizations, we propose a framework for redesigning organizational processes and for developing appropriate design information systems. The paper describes work on a larger on-going research project at the Harvard Design School on intra- and interorganizational design information systems.

Keywords: computer supported cooperative design, knowledge transfer, process modeling, organization theory, agency problems.

1. Introduction

The increasing fragmentation and growing specialization in the building industry has led to a division of design activities and responsibilities across organizational boundaries, and resulted in communication and contractual barriers among the participants. Recent developments in computing and the emergence of networking phenomena such as WAN, ED! and Internet provide a promising situation for overcoming these problems, while necessitating in research a shift from isolated desktop computing thinking to a social computing approach [Mitchell 1995]. Recent research in computer supported cooperative design (CSCD) addresses this shift. However, most of the research efforts in these areas focus on the technical aspects of cooperative design, such as standards for communication, product and information models, and user interface systems, while the underlying organizational and contractual processes have been widely neglected.

This paper addresses these organizational problems. It is based on our belief that an understanding of the organizational processes in building design will lead to a better and more effective development of appropriate design information systems. The remainder of this paper is organized as follows. Section 2 defines the problem of design organizations as a problem of collocating knowledge and decision right. In section 3 the components of organizational costs are described: the cost of knowledge transfer and agency cost. Finally, section 4, discusses the implications of the proposed organizational model for design information systems.

2. The Problem of Design Organizations

Designers have limited knowledge at two levels. First, there is the feasibility frontier of technology, which depends on the knowledge available at any given time [Pollalis and Bakos 1994]. Second, there are limitations specific to each individual, which March and Simon termed "bounded rationality". Accordingly, humans' sensory and mental faculties are a scarce resource with limited storage, processing, and input/output capabilities [March and Simon 1958]: knowledge possessed by any individual designer is limited to a small subset of the existing state-of-the-art knowledge known to humanity.

This limitation of the individual's mental and sensory faculties makes it impossible for the designer (in the following referred to as she) to make every detailed design decision in the building design process personally. In particular, with the growing specialization and globalization of the profession, she must increasingly rely on the specialized and local knowledge of other participants in the field, such as the engineer, the local subcontractor or the manufacturer, to make detailed design decisions. As a result she faces the following choice. Either she gathers as much information as she can from these specialists to make design decisions herself, or she delegates decision authority to the participant who possesses the appropriate knowledge.

Design situations which requires knowledge that is transferred at low cost, such as price and quantity information, calls for the first solution. In situations, however, in which specific ("sticky") knowledge is involved, such as how to solve a complex detailing problem, the second solution, delegating decision rights to the specialist, is appropriate, as the cost of transferring this type of knowledge is high [von Hippel 1990].

The problem of design organizations is thus defined as a problem of collocating decision rights with the relevant specific knowledge; and the structure of design organizations as an efficient response to the structure of its information costs [Jensen and Meckling 1991]. According to this definition, a change in information cost (e.g. through the introduction of new design information systems), must parallel a change in organizational structure.

3. Knowledge Transfer and Agency Cost

If all information could be shared at zero cost, and if there was no divergence between the goals and objectives of the design actors (as is assumed by traditional microeconomic models) then the problem of collocating decision rights and knowledge would assume no importance. However, the transfer of knowledge is costly, and design actors have divergent interests resulting in agency cost.

3.1. COST OF TRANSFERRING KNOWLEDGE.

A designer attempting to gather the requisite knowledge to make every detailed decision herself will pay the cost of gathering and moving every single piece of knowledge necessary to make the decision. Further, she is likely to commit errors due to her bounded information processing capability.

We use knowledge here to denote all knowledge required to make design decisions; i.e. not only internal knowledge held by the designer (what is typically labelled "design knowledge" in traditional CAAD research), but also, and in particular, external knowledge not possessed by the designer due to her bounded rationality. Further, by transferring knowledge we mean effectively transferring knowledge and not just passing information. The simple borrowing of a CAD programming manual, for example, is not sufficient to transfer programming knowledge to the recipient.

The cost of transferring knowledge depends, to a large extent, on the nature of knowledge transferred. Figure 1 illustrates the continuum of the different types of knowledge involved in design decision making. At one end of the spectrum is explicit knowledge which is transferred at low cost. As knowledge becomes more tacit, the cost of transferring knowledge increases.

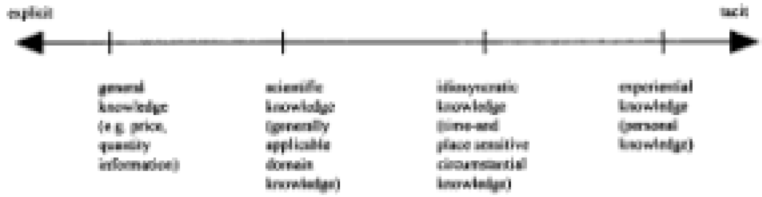

Figure 1. The spectrum of knowledge in building design ranging from explicit to tacit knowledge.

We distinguish between general, scientific, idiosyncratic, and experiential knowledge which are described in more detail below. While general knowledge denotes the most explicit type of knowledge and is transferred at low cost, the three other types of knowledge, scientific, idiosyncratic, and experiential are located in the continuum between explicit and tacit knowledge and are costly to transfer. In design, the different types of knowledge are:

(1) General Knowledge. Examples of explicit knowledge are prices and quantities -the manufacturer can easily tell the designer the price of standard building products or she can look them up herself in a product catalog. However, even this explicit knowledge is not transferred completely without cost. The input of data into product

catalogs is time-consuming and, because of the time-sensitive nature of the data, requires continuous update [Pollalis 1994]. In practice, the process of putting data into catalogs resembles often a Sisyphus task: the data changes faster than can possibly be updated.

(2) Scientific Knowledge. Scientific knowledge is costly to transfer to nonscientist or scientist in different fields because of its implicit references to rules about cause and effects known only within its particular scientific domain. For example, the technical properties of a structural steel member (the forces, inertia, and so forth) which might be crucial for deciding a facade system are not easily communicated to the architect, the owner or the electrical engineer.

(3) Idiosyncratic knowledge. Idiosyncratic knowledge includes knowledge of specific local site conditions, skills and preferences of individuals, the peculiarities of specific machines and particular design opportunities. This information is often place sensitive and perishable, and thus very difficult to transfer. For example, knowing about the availability of an attractive vacant site is only useful if it is acted upon immediately. If this information is not used immediately it may become useless.

(4) Experiential Knowledge. Experiential knowledge is acquired through personal experience. It combines intuition, judgment, common sense, and the capacity to do something without necessarily being able to explain it. The exercise of skills such as sketching, using a CAD program, and craftsmanship are examples. Experiential knowledge requires costly learning processes to transfer.

3.2. AGENCY COST

From this description of knowledge, it seems that design decisions are best made by the participant in the field who has the best (tacit) knowledge for the particular decision. This would be true if the objectives and goals of the design participants were perfectly aligned. However, in a realistic setting, assigning decision rights is not so simple. The designer confronts a problem deriving from what is commonly called agency costs [Jensen and Meckling 1976].

An agency relationship is an agreement under which one party, the principal, engages another party, the agent, to perform some service on the principal's behalf. In the context of the design organization, agents are consultants, engineers, manufacturer, and surveyors, who are engaged to exploit the economics of specialization.

Agency costs are the costs that result from the incentives agents have to take actions that increase their well-being at the expense of the principal. Agency theory argues that this occurs (I) because of the divergent (self-) interests of principal and agent, and (2) because the principal cannot perfectly and costlessly monitor the actions and information of the agent (information asymmetry).

Consider a structural engineer to whom design decision right is delegated. Let us assume the decision right involves the authority to determine the diameter of a column. In this example, the designer is the principal and the structural engineer is the empowered agent. Given the choice between two possible diameters for the column, a larger one, which the structural engineer can recommend from the top of his head, and a thinner one, which corresponds better to the original design intent (e.g. "an elegant solution"), but which would require additional calculations, he is likely to select the first, because of his natural interest to avoid risk and maximize profit. We assume here that making a "safer" choice will involve less calculations, thus increasing the profitability of the agent's service provided. Further, we assume that there are no personal or professional profits to be made by recommending a "daring" solution. In order to obtain the elegant solution, the principal (the designer) must incur additional costs which corresponds to the agency costs.

More generally, the components of agency costs are:

(I) Monitoring costs incurred by the principal to observe the agent's actions. Monitoring refers to direct observation, such as on-site supervision of subcontractors' activities, or the establishing of appropriate control mechanisms, such as shopdrawing processes, which ensures the designer that the manufacturer's details or materials correspond to her design intent.

(2) Bonding costs incurred by the agent to make his or her service more attractive. The agent might buy insurance premiums to guarantee that he will not take adverse actions or to ensure that the principal will be compensated if he does so. In today's practice the bonding capacity of agents, such as engineers, specialist engineers, manufacturers is often an essential part of their service offerings.

(3) Residual loss. Usually it does not pay to resolve the incentive conflict completely. Residual loss is the effective loss that results despite the bonding and monitoring costs incurred.

4. Implications for Design Information Systems

We have defined the problem of design organization as a problem of collocating decision rights with relevant knowledge, and have described its components in detail: the cost of transferring knowledge, arising from the "stickiness" of scientific, idiosyncratic and experiential knowledge, and the costs due to the opportunistic behavior of the agent, the agency costs, composed of monitoring costs, bonding costs and the residual loss. Acknowledging the existence of these organizational costs provides us with a framework for an understanding of design organizations which takes into consideration the limited rationality, the self-interests, and the natural conflicts of design participants. This framework implies several things for the design, development and implementation of design information systems.

Firstly, it gives us a theoretical explanation for why existing cooperative design information systems have not been taken up so readily by the building design industry: the existence of high agency cost and knowledge transferring cost undermines their effective use, despite their availability and maturity. This is consistent with results from our field studies which suggest that the main barriers for electronic design collaboration are not technical, but organizational: reluctance and "lack of incentives" of participants to share knowledge, and "impossibility to explain matters on the screen" [Huang 1995].

Secondly, it indicates that the development of design information systems is not simply a technical task to be left to systems analysts, programmers and software developers. It demands an integrative approach that takes into account the organizational costs. Design information systems should aim at either reducing the cost of knowledge transfer, the opportunistic behavior due to agency behavior, or both. In our research unit at the Harvard Design School, we have designed the following three example design information systems, which address these issues.

(i) A shared project-centered database which tracks data entries and status of documents. The benefits of this "Project Information Center" are increased overall transparency and reduced monitoring costs. The shared database further cuts bonding costs, by encouraging a shift from multiple, individual insurance coverage to a single wrap-up (project) insurance policy. This is less costly, because it eliminates redundant, overlapping coverage; further increased transparency makes risks better observable to insurance companies, who in turn are ready to lower insurance fees.

(ii) An on-line three-dimensional CAD model with integrated groupware/discussion databases. This "3D Groupware" provides a platform for concurrent schematic design and design development. Communication among engineers, architects, manufacturers, and owners are facilitated by discussion databases directly attached to three-dimensional building parts. Specific knowledge of participants are thus transferred to a shared model on a "middle ground". The tacit knowledge of these specialists are referred to by semi-structured searchable pointers. This keyword-like knowledge index points to the corresponding parts of the three-dimensional geometric model, and is referred to from relevant discussion database entries. It enables quick access to relevant specific knowledge for particular design decisions.

(iii) Finally, an "Electronic Marketplace" on the World Wide Web for buying and selling building products and materials, and for exchanging building design expertise [Bakos 1991]. Open to a prequalified "trusted" community, the electronic marketplace employs market coordination mechanisms for "automatically" collocating decision rights with the relevant knowledge/information (Figure 2).

For a more detailed description and discussion of these design information systems see [Huang 1997].

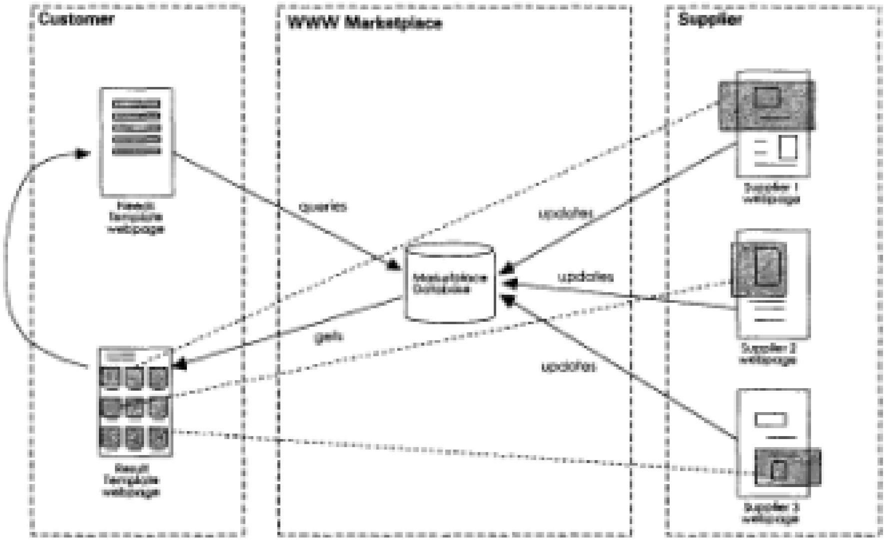

Figure 2. Architecture of the WWW electronic marketplace developed at the Harvard Design School. The efficiency of the marketplace design derives from the combination of optimized distribution of critical product/expertise data and the use of semi-formalized templates.

Thirdly, it gives us guidelines for designing future computer-supported organizations. An example application in this direction is the "process handbook" for building design we are currently developing. The process handbook is a tool and methodology for redesigning organizational processes systematically based on coordination theory [Malone et al. 1993]. We decompose the building design process into its core activities and dependencies, and analyze how these dependencies can be managed by alternative, computer supported coordination processes borrowed from other industries, such as the automobile, the aerospace, the consulting and the software design industry. Our framework of knowledge and agency costs provides us with valuable selection criteria for choosing among the alternative coordination processes and for adapting those to building design.

Finally, we believe that in future computer-supported design networks, replacing human agents with intelligent or autonomous computer agents will not reduce, but augment the agency costs described in this research (at least the first generation of computer agents). These agency costs arise primarily because users are not likely to trust computer agents immediately and completely, and will thus incur necessary monitoring and bonding costs. Thus our organizational model provides us with a framework not only for present human participants, but offers guidelines for an effective management of future computer agents. We are confident that the designer will play a leadership role in the emergent networked design practice, if he or she succeeds to leverage distributed specific knowledge from human and computer agents effectively, and delegate decision rights wisely.

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