Construction Process Improvements in Market Networks

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ABSTRACT

Most construction projects are carried out in market networks with several design and production firms involved. It is unlikely that the use of information technology (IT) will proceed at an even pace in firms. A vital task in coordinating the construction process is therefore to bridge technology gaps between firms. The analytical framework for this investigation is derived from the theory of transaction costs, with focus on how network participants perceive incentives for sharing and preserving project information. Issues such as information feedback from later to earlier stages of the process and professional liability for information provided are dealt with in this context. The main points are illustrated by results from recent and ongoing Swedish R&D projects within the field. Emphasis on IT use at the client/designer interface and at the construction site interface is expected to grow. Improved digital telecommunications for rapid transmission of graphics with attached databases are seen as a development with far-reaching consequences for efficiency in the construction process.

Key Words

construction process; networks; transaction costs; design feedback; Swedish construction

INTRODUCTION

Process improvements through time compression (Stalk and Hout, 1990) and improved process quality by means of better use of information technology (Rockart and Short, 1991) have come into focus in recent years. Better use of computers and advances in telecommunications promise improvements in speed and accuracy in the total construction process by integrating design specialists and by integrating the design flow with flows through later stages of the process (Koskela, 1992). Many firms and individuals are involved in each construction project, interacting in a market network; when looking at the forces that will change ways of designing and building, we must start by acknowledging that the behaviour of each participant will be understood best if we assume that process improvement has to do with different processes in different businesses. The "construction process" should be seen as an arena where all these processes meet. The

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problem to be addressed here is how firms in a network strike a balance of intraorganizational and interorganizational uses of information technology.

Networks of collaborating firms can be viewed as a particular, hybrid form between market and hierarchical organization, and the existence of networks as well as their efficiency can be explained from a coherent basis formed by the two categories of production costs and transaction costs (Williamson, 1991). Thus the frequency, uncertainty and specificity of assets dedicated to a particular transaction are assumed to influence the costs associated with market contracts. Certain features of the construction sector are particularly relevant when analysing how information technology supports the creation and sustainment of networks. Taken individually, these features are to be found in other industries, too, but as a whole, they set construction apart. Barriers to market entry are low in construction, and many firms deliver similar services or products; as a result, we have a fragmented industry where capacity use determines prices in the short run. The costs of centralized collection of information are high, and as a consequence, decisions and market information search tend to be decentralized within firms. High inspection costs can be assumed to lead to partnership problems such as shirking, which is only partly offset by a high degree of customer involvement - which in its turn gives a construction process with considerable elements of iteration and redesign. Main features of the construction sector can be matched by main aspects of information technology (Bröchner, 1990a). Here, we shall go directly to the forces that affect the ties between intraorganizational process improvement and interorganizational networks.

Intraorganizational Process Improvement

Increased use of information technology within processes in firms has usually begun by internal rationalization of manual procedures while external pressures from customers and suppliers have been of secondary importance. Today, the need for employee involvement and for efficiency in implementation explains why information systems development in firms is supposed to emanate from the basic and probably unique business idea of the firm. A vertically integrated firm with a specialized technology, controlling within that speciality several stages of the construction process and beyond that into facilities management, will tend to evolve a characteristic set of internal processes. Other firms stay within a single stage of the construction process while offering information technology support for both earlier and later process stages. A majority of firms will be even less integrated across stages. This uniqueness and mix of process stage involvement, which may stem from a wish to avoid pure price competition, complicates the development of industrywide standards for the handling of information in construction projects.

Bridging Gaps in Information Technology

It is reasonable to expect a conflict between the pursuit of process improvements within the firm and in a network of firms. An opportunity to increase the ability to bridge information technology gaps between organizations involved in construction projects is given by the trend towards better documentation of internal routines and information flows as part of quality assurance and management systems in construction firms. On the other hand, a documented quality system may freeze routines and organizational responsibilities in accordance with task patterns that reflect quickly obsolescent information technology.

Great steps forward in the implementation of information technology in networks are to be expected when capacity use is high in the construction sector. On the contrary, when there is widespread excess capacity, suppliers and contractors operating with a greater proportion of unstructured, manual routines will be able to offer attractive prices for their services, undercutting those who invest in information technology. From the overall viewpoint of efficiency in the single construction project, such opportunities cannot be overlooked. It puts special demands on coordinating firms in construction that they have to be able to bridge between participants with different levels of information technology sophistication. This is not made easier when the process stage dependence is complicated. Efficient design-and-build arrangements with specialized contractors may include a number of specialist contractors who manage and prefer to integrate design and execution capabilities, whereas others expect to be provided with design by another participant.

Although investments in company specific information technology may lead to considerable technical maturity, they may also lower the potential for further internal gains in productivity by participating in networks that impose new definitions and procedures from outside. But a minimum level of systems development must be in place. It is unlikely that bilateral agreements to use a higher level of information technology over a market boundary between two independent organizations will be efficient if the intraorganizational level of information technology use is too low. The dissimilarity between car production and construction is interesting: the success of ODETTE for communicating between European car producers and their suppliers is influenced by their preexistent internal computer systems, whereas information handling is much less structured initially in construction firms. The spread of data interchange in construction is consequently a different matter.

The presence of an early Swedish consensus on classification of information relating to construction projects, as well as nationally uniform building specifications and regulations, should facilitate the transition to structured intercomputer information flows. Therefore, efforts going into the development of building product models indicate important features of company-specific product models by pinpointing requirements which network integration poses. The Swedish BSAB classification system is extended in the KBS Product Model (Svensson, 1992). NICC, Neutral Intelligent CAD Communication, is an approach which also rests on the nationwide acceptance of the BSAB classification table for physical elements - building parts (Tarandi, 1992). Expanding and modifying this classification into a product model makes it possible to prescribe a communication format for CAD geometry with "building parts" connected to alphanumeric data.

Competitive Edge versus Network Access

There is a growing awareness that information technology in itself is not a major source of competitive advantage, at least not in the long run. At best, it is a transitory position which is created in the market (Brady *et al,* 1992, Cunningham and Tynan, 1993). Lasting competitive advantage is difficult to preserve when features of the internal IT system are easily copied by other firms. In typical network cases, the main reason for firms to invest in information technology is its function as a ticket to participation in networks. The ability to remain in front of competitors when it comes to efficient application of information technology tools for internal process improvement does constitute a true advantage, provided that access to networks has been gained.

Network Expansion or Reduction

Having reached a minimum level of intraorganizational IT capability, a firm in the construction sector has to decide how to allocate resources to interorganizational systems in order to continue improving its process skills. Here, the strategic issue is how to devise an optimum mix of systems that support a great number of short-term relations and of systems that enable the firm to form long-term, very close relationships in the market. In the first case, information technology tends to expand networks by including a larger number of firms in each construction project. The second case implies a reduction in network size.

Short-Term Market Relations Requiring Flexibility

It seems that the network pattern usually found in construction projects in Sweden is driven by the client or other leading participants as they search for lowest-price opportunities in local markets for design specialists, specialist contractors, suppliers and other process participants. Owing to the slow development of basic technologies, low barriers to market entry, and more than forty years of nationally accepted classification of building parts, specifications and uniform government regulations for building, these firms tend to operate on almost identical principles within their specialities. Prices offered by an individual firm can then be assumed to mirror its expected workload for the duration of its participating in a given construction project. If firms, their products and services, are reasonably homogenous within subsectors of the industry, capacity-based price competition ensues. Empirical investigation confirms that strategies for stable alliances and working relationships between main contractors and subcontractors have been unusual in Sweden (Ehnström and Ledberg, 1991). Retaining the emphasis on short-term market relations while increasing the use of information technology in construction places high demands on system flexibility.

Most decisions and market information search are decentralized and local in Swedish firms in the construction sector, reflecting high costs of centralized collecting of information. The cost structure probably varies with construction project size, duration and market segment. Large Swedish construction firms serve a broad range of project sizes and types in the domestic market. This broad approach to the market influences their requirements for flexible information technology support. There is thus an organizational imperative for design and construction support systems: they must be flexible so that they can take advantage of market opportunities which arise locally from fluctuating levels of capacity use in potential network member firms.

Network Reduction

Very high transaction costs in setting up digital communication contracts would bring strong pressure to reduce the number of network partners, with an extreme point being integration of the construction process into single firms. Even a moderate increase in transaction costs may reduce the number of designers, suppliers and contractors involved in each construction process. However, it is easily recognized that this is also a learning process for the firms involved and gradually for the entire construction sector. The study of how new networks come into being, their duration and stability is often supported by concepts not found in the theory of transaction costs; instead, reference is made to reciprocity norms, personal relationships, reputation and trust (Larson, 1992; broad overview by Cunningham and Tynan, 1993).

In time, costs of contractually creating networks can be assumed to decline for several reasons. One reason is the evolution of a new set of legal arrangements, which will be discussed below, another is the linkage between interorganizational and intraorganizational development. In Sweden, bilateral experiments with EDIFACT messages between contractors and suppliers have been conducted since the late 1980s. Asplund and Danielson (1992) identify three intraorganizational needs: a nexus database for handling invoice payments, a shift of administrative efforts away from invoice handling on to purchase orders, and finally strict adherence to national guidelines for purchase contract clauses, as found in the Swedish AF AMA. The shift upstream of process emphasis is evident.

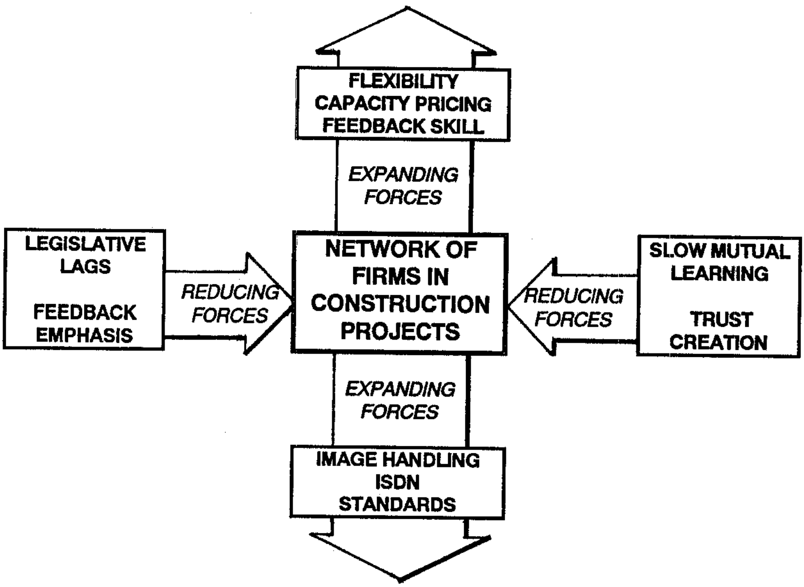

Figure 1. Interorganizational Networks: Reduced or Expanded?

Three Aspects of the Construction Process

How network participants perceive incentives for sharing and preserving project information can also be understood by returning to the theory of governance of exchange relationships. Will the network by itself and with no extra efforts in the managerial and legal context minimize the scope for suboptimization between original client needs and the finished building in use? Three aspects of the construction process are especially important in determining the balance between the forces of reduction and expansion of interorganizational networks: feedback from later stages of the process - with uncertain effects on network size; legal issues concerned with electronic transfer of messages between organizations - which mostly concerns reduced networks, and finally, the probable expansionary network effects of better graphical interfaces for visualization as well as the ability to transmit images rapidly.

Feedback from Later Stages

As pointed out initially, networks of firms engaged in a construction project should in theory be beset by classical partnership problems, notably shirking. This can be predicted wherever inspection costs are high. Active management of upstream feedback on long term behaviour of buildings and their component parts can mitigate this risk. That the incentive to capture and share experiences in decentralized and fragmented organizations is weak is a widely acknowledged problem (Peters, 1992) which is felt particularly in the construction sector. Feedback is best achieved in ongoing, constant processes, where the process is modified continuously according to differences between desired and actual results of the process. If a network is restarted for each unique project, very little hope of recovering transaction costs inherent in feedback efforts can be held by local decision makers. Only those clients which have recurrent needs for new construction can be sure of reaping the benefits of feedback schemes.

Three types of feedback content in construction should be distinguished. First, there is feedback on resource use in site activities. There is a long tradition of collecting data on activity durations in assembly and transformation processes on site, data to be used for planning purposes and cost estimates. Here, the need for classification is obvious, although a decentralized firm will not always agree on common definitions. Thus, large and decentralized participant organizations in a network may lack uniformity in their internal classification of resources, activities and building components. Although there remains a problem in conveying the production context, *eg*, human skill factors, influence of total work load and local market conditions, to other users of such data, this kind of feedback is well supported by available information technology tools.

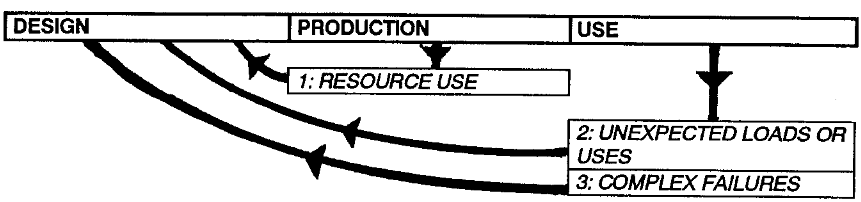

Figure 2. Three Types of Feedback

A second type concerns feedback to the design stage based on the effects of unexpected environmental load during production or use of the building, unexpected type or intensity of use of the building, unexpected operations and maintenance technologies - as well as geometric incompatibilities of building components (Bröchner, 1990b). In most of these failures, there has been design work with a singleminded attention to the primary functions of components, which has reduced the margins for unexpected contexts. For this group of feedback information, active knowledge management can be expected to be introduced by those network participants who have the most to gain from avoiding repetition of mistakes. Design reviews involving people with everyday experience of site production and facilities management, designer presence on site, technical audits of finished projects are feedback methods involving direct human interaction in knowledge transfer. Opportunities for direct interaction across stages will probably be more frequent if design times are shortened and the duration of the construction process as a whole is brought down. In addition to direct exchange of experiences, there is the transfer of experiences to documents, such as paper based standard specifications or libraries of CAD details showing complex components and parts of systems, which might also be tied to together with verbal recommendations to designers who retrieve them in order to modify for reuse in new projects. Emphasis on type 2 feedback implies a tendency to network reduction.

A third type, or a special case of the second type of feedback, is characterized by complex failures in the performance of buildings. The sick buildings syndrome is the best example of failure where training and everyday experience is insufficient in explaining the causes and identifying the means to avoid repeated mistakes. This need for scientific analysis of failures and deviations in building performance means that management of human interaction within project networks is not enough. Once the analysis has been translated into recommendations for practitioners, knowledge can be transmitted in structured ways, similar to the treatment of less complex feedback (type 2), equally dependent on sustained links in a network of firms.

Legal Issues

The importance of a number of legal issues for the implementation of information technology in networks typical of construction is evident. In order to preserve and reinforce incentives for technical and esthetic creativity, rules protecting intellectual property have to be adjusted for a situation where technical barriers are much lower than in a paper based world. The temptation for transitory network particpants to copy and appropriate design for reuse in other projects or in later stages of the same project must be handled. This applies to assignment of rights to use architectural design products in transformed versions for facilities management purposes. Rapid interactive design with contributors from several firms also complicates liability. One possibility is to label each contribution to the common database according to origin, in fact treating each change as a separate message with an identified source certified by an electronic signature. Unfortunately, this is cumbersome and may be too slow for iterative redesign with pretensions to creative interactivity.

Heightened intensity in an interactive process is more than a matter of changing business practices. New contractual patterns are necessary, while legislation still mirrors a paper based viewed of documentation. There are many reasons to believe that the momentum of transaction costs will be shifted upstream towards early stages in the construction process, as well as to the more permanent creation of networks that outlast single projects. Early signs that costs associated with establishing and maintaining contracts with customers increase in semiconductor industry networks (Hart and Estrin, 1991) correspond to what suppliers to construction firms should be experiencing.

If legislation lags behind in matters such as the acceptance of electronic signatures, the implementation of information technology in construction will be delayed. There is also a need for development of new industrywide standard practices: a new contractual pattern in construction has to be created, to judge from EDI experiences. Interchange, communications and trading partner agreements acquire a vital role in defining the legal security of network participants. All this enables firms to work more closely together. It is a heavy task to devise and monitor bilateral agreements between firms in the industry. Great emphasis is placed on trust to achieve a situation where the heavy, front-loaded transaction costs involved in bilateral contracting can be recovered. Networks will tend to be small and exclusive in the absence of legislation and generally acknowledged business practices. The presence of a high proportion of resources dedicated to particular bilateral, project unique sets of agreements will predictably lead to greater integration in an industry. To take an example, design specialists would tend to gather under a single organizational roof, where social pressures will be more efficient than recourse to legal and market sanctions in the event of design and planning errors.

Communicating by Image

New and better tools that support visualization appear steadily on the market. There are several reasons why greater ease in producing and handling images will increase emphasis on the use of information technology at the interface between client and designers as well as on the construction site. Visualization supports and shortens the time spent on the numerous learning processes included in each construction project. Early use of images facilitates the forming of new personal relationships and of trust. More rapid and user-friendly tools are an advantage in iterative design with many participants, just as it lowers transaction costs for onsite coordination of specialized contractors, equipment and deliveries. Visualization also promises more efficient ways of preserving project information so that it can be easily retrieved and reused.

Although it can be claimed that visualization should be treated as a consequence of stage-integrated building product models, process efficiency can be raised already by the use of stand-alone systems. A current Swedish project deals with visual support for interactive planning during site meetings with contractors belonging to the project network (Frisk and Gustafsson, 1993). When each meeting is finished, participants receive a revised site layout with attached notes. Tests indicate that this is an efficient way of pooling production experiences.

The recording of a multitude of last-minute changes in the execution of construction work puts technical strain on participants and systems. Detailed revisions in existing CAD systems have often been seen as too slow, and the method for transferring revisions to participants and site personnel has tended to be a recourse to pencil and photocopier or to oral communication of changes, rather than a straightforward updating of drawings. Dependable as-built records improve the transfer of information to the post-construction stage of the total process.

Improved digital telecommunications for rapid transmission of graphics with attached databases holds consequences for efficiency in the construction process. Today, CAD files are sent by post between design specialists in small construction projects, and it is often a slow and difficult procedure when transmitting complex images over the existing telecommunications links, especially to temporary construction sites. Therefore, the promise of high speed, broadband services such as ISDN is of great importance for process improvement.

CONCLUSIONS

There are strong reasons to believe that the network nature of most construction projects will keep its superior efficiency in market allocation of excess capacity among specialist firms. Although a full exploitation of present capabilities of information technology in construction seems to call for a higher degree of corporate integration, due to high transaction costs for market relations between firms, progress can be made by acknowledging the need for supporting a bargaining process with considerable flows of interfirm messages. Two major obstacles to the implementation of more efficient processes in construction have been identified here. One is contractual and legal, namely the difficulty in keeping pace with information technology developments when legislating and redesigning business practices to support interorganizational message flows. The other obstacle is technical and has to do with the need for bandwith in telecommunications and accepted standards so as to provide rapid means for exchanging images between technical specialists and between office and construction site.

It is not unlikely that we will witness shrinkage in construction networks as well as increased permanence in relations, at least as a first stage. Information technology is ambiguous in its effects on networks. With further development of information technology itself and the development of both legislation and business practices that allow better exploitation of the technology, networks should expand again and perhaps also be more transitory, project-bound or rapidly altered according to process stage within the same construction project. Accordingly, there will be many occasions for firms to reconsider their mix of intraorganizational and interorganizational uses of information technology.

References

Asplund, E and Danielson, U (1992), Digital handel i byggföretaget [Digital trade in the construction firm]. In Swedish. Siab AB. Draft version. November.

Brady, T, Cameron, R, Targett, D and Beaumont, C (1992) Strategic IT issues: the views of some major IT investors. *Journal of Strategic Information Systems,* Vol 1, No 4, pp 183-189.

Bröchner, J (1990a), Impacts of information technology on the structure of construction. *Construction Management and Economics,* Vol 8, pp 205-218.

Bröchner, J (1990b), Integrerad erfarenhetsåterföring [Integrated feedback]. In Swedish. In *Byggprojektet som dataförädling [The construction project as value-added to data]* (ed J Bröchner, A Eriksson, J Lundequist). Royal Institute of Technology, Stockholm, pp 41-52.

Cunningham, C and Tynan, C (1993), Electronic trading, interorganizational systems and the nature of buyer-seller relationships: the need for a network perspective. *International Journal of Information Management,* Vol 13, No 1, pp 3-28.

Ehnström, J and Ledberg, K (1991), Producera med egen personal eller anlita underentreprenörer [Producing with employees or subcontractors]. In Swedish. MSc (CE) thesis, Royal Institute of Technology, Dept of Building Economics and Organization. October.

Frisk, B and Gustafsson, G (1993), Bygg- och UE-samordning med flexibel - datorstödd - APD-plan [Contractor coordination using flexible, computer supported site plan]. In Swedish. FoU-Väst Rapport 9302. Byggmästareföreningen Väst.

Hart, P and Estrin, D (1991), Inter-organization networks, computer integration and shifts in interdependence: the case of the semiconductor industry. *ACM Transactions on Information Systems*, Vol 9, No 4, pp 370-398.

Koskela, L (1992), Application of the new production philosophy to construction. Center for Integrated Facility Engineering, Stanford University, Technical Report No. 72. September.

Larson, A (1992), Network dyads in entrepreneurial settings: a study of the governance of exchange relationships. *Administrative Science Quarterly*, Vol 37, No 1, pp 76-104.

Peters, T (1992), *Liberation Management: Necessary Disorganization for the Nanosecond Nineties*. Knopf.

Rockart, J F and Short, J E (1991), The networked organization and the management of interdependence. In *The Corporation of the 1990s: Information Technology and Organizational Transformation* (ed MS Scott Morton). Oxford University Press, pp 189-219.

Stalk, G, Jr and Hout, T J (1990), *Competing against time: how time-based competition is reshaping global markets*. Free Press.

Svensson, K (1992), Neutral building product model for computer integrated construction ("The KBS Model"). In *Computer Integrated Construction* (ed H Wagter). Elsevier Science, pp 11-16.

Tarandi, V (1992), Neutral intelligent CAD-communication (NICC). In *Computer Integrated Construction* (ed H Wagter). Elsevier Science, pp 61-68.

Williamson, O E (1991), Comparative economic organization: the analysis of discrete structural alternatives. *Administrative Science Quarterly*, Vol 36, No 2, pp 269-296.

c. 1993, Management of Information Technology for Construction, K. Mathur et al (Eds), World Scientific Publishing Co., Singapore.