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Information Technology and Purchasing Strategy: Two Necessary Enablers of More Efficient Construction Processes

By

Martin Ekstrom & Hans Bjornsson

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STANFORD UNIVERSITY

If you would like to contact the authors, please write to:

c/o CIFE, Civil and Environmental Engineering Dept.,
Stanford University
Terman Engineering Center
Mail Code: 4020
Stanford, CA 94305-4020

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1. Introduction

"Faster, better, cheaper", these are the goals for all construction industry managers. At their disposal, they have a set of strategies in the areas of business process re-engineering, information technology, and purchasing strategy. They can, for example, increase the amount of concurrent engineering to save time, solicit bids from more subcontractors to save cost, or invest in visualization tools that facilitates communication among the project stakeholders to improve quality. However, in isolation, all three of these measures can have unexpected side effects. First, concurrent engineering can cause an explosion amount of information needed to coordinate the activities. Second, a low bidding subcontractor can turn out to be a "change order artist." Third, it may be difficult to find architects and subcontractors that are willing to invest in the visualization tools if they are employed only on a project basis. Experienced managers will implicitly or explicitly be aware of such consequences, and are therefore understandably hesitant towards taking radical measures to improve performance. In a competitive environment where the success of the ongoing project is everybody's primary concern, this complexity and interconnectedness of change efforts is likely to add to the industry's inertia. In this context, it is interesting to compare the development in the construction industry to that of other industries, in terms of IT investments and productivity. We can, for example, observe that during the past 30 years, the overall industry sector in the US has experienced substantial improvements in overall industry productivity, along with increased information technology investments (Figure 1). At the same time, while it has been shown that the individual construction trades have experienced productivity improvements [8], there is little evidence that the overall productivity of the construction industry has increased in the same manner as in other major industries. Several studies, such as Gullickson and Harper's [9] (Figure 1), have even shown negative productivity for the construction industry. Moreover, as is also illustrated in Figure 1, the construction industry also lagged behind when it came to IT investment (measured as a percentage of total fixed investments.)

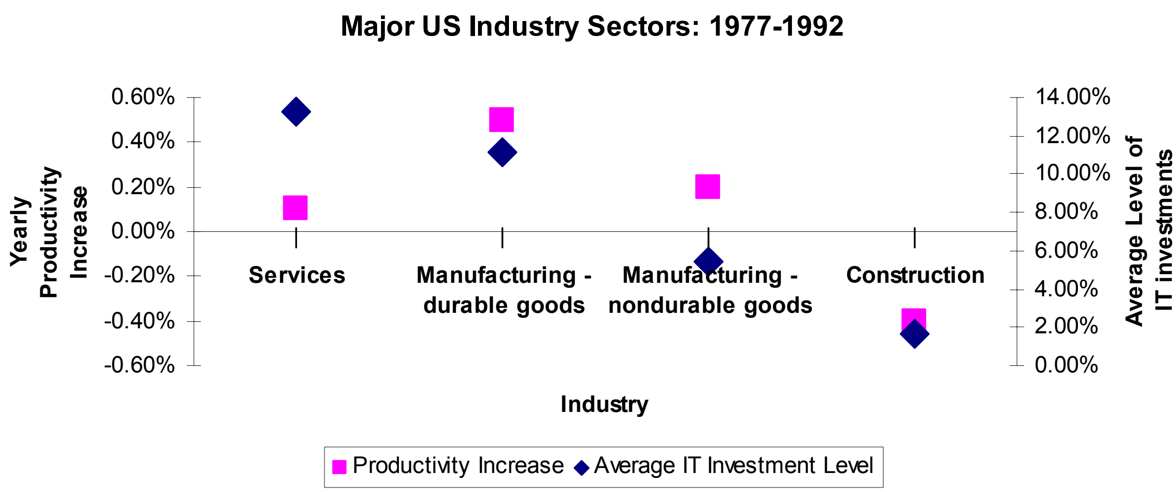

Figure 1 The left y-axis shows multifactor productivity for construction along with some other major US industries (Based on data from bureau of labor statistics analyzed by Gullickson and Harper [9].) The right axis relates to the development of IT investments as a percentage of fixed nonresidential assets during the same time period (Based on data from the Bureau of Economic Analysis [12].)

Several authors [10, 11] have put forward the use of information technology as one reason for the productive increase in other industries. Along the same line of reasoning, the above presented data suggest that the lack IT investments is a plausible cause of the construction industry's poor productivity performance.

Nevertheless, IT is becoming increasingly complex and integrated with the core business, and it cannot any longer be viewed as an isolated function. Other industries, such as manufacturing, has not only seen an increase in IT spending, they have also experienced, two changes in the organizations production activities. Large and vertically integrated organizations have outsourced many activities. More importantly, there is a distinct trend towards deeper integration with a fewer number of suppliers. This move towards a relational rather than a transactional mode of contracting has enabled buyer and sellers to profit from efficiencies due to mutual adaptations. Several authors (e.g., [13, 14]) have shown that information technology such as ERP systems often serve as facilitator of these relationship specific adaptations. When combined these two trends can be described as a move towards a 'virtual organization [15]

The project centered construction industry, has experienced neither the increase in IT spending nor the organizational restructuring found in other industries. In the

Architecture/Engineering/Construction (AEC) industry, each project is associated with a unique, temporary network of client, architects, engineers, contractors, subcontractors, and material suppliers. Stinchcombe [16] observed that while traditional manufacturing involves mass production of *standardized tasks* construction projects involve *standardized components*. According to Dubois and Gadde [4] the project centric nature of the construction industry results in 'few individual inter-firm adaptations' beyond the individual construction project and the reliance on 'short-term market' based exchange. They also argue that the lack o f tighter couplings between the different organizations prevent innovation. Still, even though loose networks of contractors and subcontractors have characterized the construction industry, these constellations often form long lasting relationships [16, 5]. It is also important to consider the changing nature of information technology. Traditionally, information systems that integrate different members of the supply chains require large investments from the involved organizations, in terms of technology as well as the reengineering of business processes. The advent of the Internet, and web-services enabling "plug and play" connectivity promises the facilitation of data exchange in temporary supply chain structures [18]. As a result, companies could reap the benefits of technologies investment without making relationship specific adaptations and investments. Will standardized Internet technologies permit the construction industry to profit from the strategic operational efficiencies associated with IT, without changing its current mode of contracting? Or is organizational change a prerequisite for successful adoption of IT in AEC?

One way to investigate such questions is to view both information technology and purchasing strategy as facilitators of changes that can help an construction and engineering company to fulfill its business goals. In this paper we focus, on two types of re-engineering strategies, concurrent engineering and outsourcing to low cost countries and how they relate to the alignment of contracting and IT strategies. Concurrent engineering offer substantial schedule savings but can also result in more communication and the potential of being locked-in to a relationship with a misbehaving business partner. Apart from concurrent engineering, outsourcing to low cost region is another re-engineering strategy that has lately won increasing popularity in construction, as well as other industries. In a global economy, construction companies have recently became increasingly interested in locating routine activities to places and countries that enjoy comparative cost advantages. However, in the absence of the re-alignment of information technology and purchasing strategies, this strategy would probably not be feasible given the extra communication costs and contractual uncertainties.

In the next section, we provide a model how both the deployment of information technology and adaptations of purchasing strategy can serve as enablers of business process re-engineering to improve competitiveness in the construction industry. The model includes elements from transaction cost economics applied to the re-engineering projects in AEC. The presentation of the model will be followed by a case study that investigates the mitigation of transaction costs in the context of re-engineering the structural steel design and procurement process.

2. Applying transaction cost economic to investigate consequence of re-engineering projects in the construction industry

Transaction Cost economics provides a useful framework to analyze the slow adoption of electronic commerce in business to business. In his 1937 article “Nature of the Firm” Coase [19] argues that the structure of a firm is set up to minimize overall transactions costs. Firms should conduct internally only those activities that cannot be procured more cheaply in the market. As a result, a firm will expand precisely to the point where "the costs of organizing an extra transaction within the firm becomes equal to the costs of carrying out the same transaction by means of an exchange on the open market." Building on Coase’s work, Williamson [20] sums governance (transaction) and production costs to measure the aggregate performance of a governance structure. The two major governance structures are “market” and “hierarchy.” “Market” refers to the free market where each production activity is performed by a separate firm (cf. competitive bidding) while a “Hierarchy” implies a command hierarchy, with vertical integration of production activities within one organization (c.f. subcontracts self-performed by general contractor). In addition, Williamson recognizes the importance of hybrid organization forms (like long term contracting, reciprocal trading, and franchising), which are characterized by a mix of markets and hierarchies. He shows how transaction costs are a function of asset-specificity and puts forward transactional hazards as the major cause of transaction costs.

Asset-specificity occurs when investments required by the two parties involved in a transaction cannot be redeployed to alternatives uses outside the specific transaction. The concept can also be linked to research in purchasing management where technical, administrative, and knowledge-based adaptations made in a customer-supplier relationship [21] constitute important forms of asset specific investments. Furthermore, asset-specificity, in combination with the simultaneous presence of two pairs of factors (bounded rationality-uncertainty/complexity; and opportunism – small numbers), gives rises to transactional hazards that ultimately cause market transactions to fail. Transactional hazards include quality shortfalls, ex-post bargaining over surplus, litigation, hold-up costs, and wasted investments.

Several studies have investigated the impact of information technology on the transaction costs and the organization of production activities, in industries other than construction. Malone et al [22] presents a model predicting that the efficiency gains caused by information technology would lead to the increased use of markets as the mode of transaction at the expense of vertical integration. Bakos and Brynjolfsson [23], on the other hand, present an economic model that explains the move towards tighter supplier integration. Moreover, empirical studies have shown some evidence for information technology causing firms to shrink [24]. According to the “The move to the middle hypothesis” [14] information technology leads to a decreased vertical integration, as well as direct market procurement in favor of a hybrid organizational form. In these hybrid networks or “virtual organizations” independent firms form close and long lasting alliances.

One problem with studies based on transaction cost economics is that they often take an industry level approach and therefore do no not differentiate between the different types of technologies. The organizational impact of a standard based bidding application is, for example, very different from the impact of a customized logistics system. It is evident that large and highly relation specific investments, such as the former, for which, in addition, the benefits are long term and difficult to quantify, are unlikely to occur within the context of an arm’s length relationship.

Another problem with the studies of the impact of information technology from a transaction cost perspective is that they disregard information technology as an enabler of new products and services. In the context of procuring specialized components for process plants, Arnold [25] has, for example, shown how an Internet based information broker can serve to reengineer the design process by enabling supplier to perform the engineering analysis as a web service. If the value of these new products is substantial they may overshadow any increases in transaction costs. Nevertheless, the focus of this paper is information technology as an enabler of re-engineering that aim at making existing processes more efficient.

We draw upon transaction economic theory in order to create a model that explains the adoption of IT and its relationship to purchasing strategy in the engineering and construction industry. The purpose of the model is to provide a framework that is consistent with the observed and expressed rationale of AEC decision-makers. In the model, business process reengineering is the major driver of change in the industry. Construction companies would like to re-engineer their business processes in a way that maximizes their competitive position by offering faster, cheaper and better products and services. However, everything else remaining equal, the re-engineering in itself are likely to result in transaction cost increases, that outweighs the advantages. The major transaction costs being [C]:

Communication Cost: The cost of communication to coordinate activities.

Opportunism Risk: The risk that a supplier or buyer will hold-up a transaction partner to renegotiate a contract.

In the construction industry, time specificity is of particular interest, and we will therefore illustrate the emergence of transaction costs in the domain of concurrent engineering. Activities such as design and detailing are often highly interdependent. If each task is relying on a large number of outputs from other tasks, there is no natural sequential order in which the project can be executed. For example, in theory a building contractor would like to integrate design and construction to compress schedule. However, if they currently procure design and subcontract most construction on a competitive basis, the change is likely to lead to increased communication costs and opportunism risks, as both the amount of information exchanged and the dependence between the activities increases. However, adaptation of the purchasing strategy and deployment of information technology can serve to mitigate the transaction costs and therefore become enablers of change process. In this case, information technology can decrease the cost of information exchange, and entering into long-term contracts with architects and key subcontractors can reduce the risk of opportunistic behavior. What further complicates the issue is if the information exchanged between the interdependent activities is uncertain (Yassine et al 1999). Otherwise, the designers, could, assume the value of the missing information and proceed, since they could be fairly certain that the interdependencies would only lead to minor adaptations down the road. Figure 2 provides an illustration of what could happen if a general contractor moves towards concurrent engineering without changing neither the contractual nor the IT environment. An activity, such as detailing, is subcontracted on a project basis. The diagrams show the production cost for the activity to be independent of time specificity (k) while the transaction cost and thus also the total costs (TC) are an increasing function of the time specificity. Let us now assume that the general contractor strives to bring down complete by beginning detailing before design is completed. The rational behind increasing the amount of parallel work is to reduce the production cost (or the time to complete the project) from PC_0 to PC_R, which will in turn reduce the total cost from TC_0 to TC_R. However, the re-engineering also has the unintended impact of increasing the time specificity from K0 to KR as the activity becomes increasingly inter-dependent with other activities. The net result is that the total completion cost increases from $TC(K_0)$ to $TC(K_R)$.

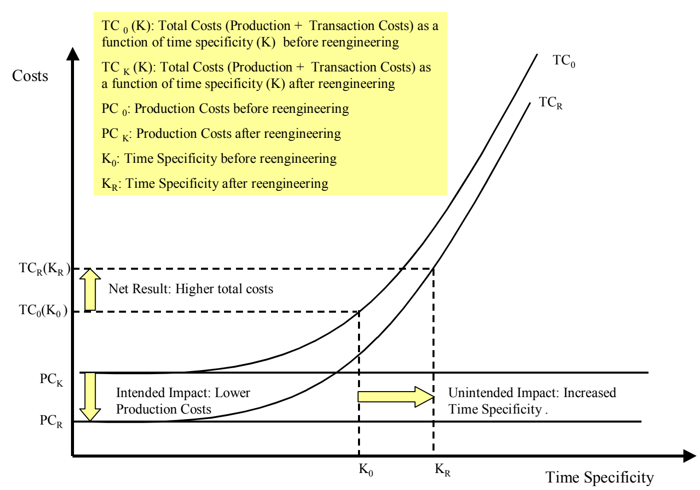

Figure 2 Potential Impact of move to concurrent engineering in AEC. The desired time savings are offset by higher transaction costs as a result of the increased time specificity of the activities.

One can argue that this situation is in general the case, since otherwise competition would have driven most general contractors to increase the extent to which design and detailing are executed in parallel. As discussed above, there are two ways buyers to mitigate the potential increases in transaction costs that potentially occur as the result of reengineering efforts.

Contracting Strategy – Increase the degree to which the activity, or parts of the activity, is vertically integrated. The general contractor can either increase the scope of work performed in-house or move towards long term contracts with the suppliers or subcontractors.

Information Technology – Reduce the cost of communication cost by reducing the cost of exchanging information. In addition, IT can reduce the ambiguity and uncertainty of the information exchanged between the transaction partners. However IT investments can also require asset specific investments, as the following case study will show.

The next section describes and analyses the deployment of IT and the change of contracting strategy to mitigate transaction costs in the re-engineering of the of the structural steel engineering and procurement process.

3. Case study: Applying Transaction Cost theory to study IT deployment as a support of business process reeingineering in construction

We conducted a case study that focused on the structural steel design, procurement and fabrication process at a global Engineering, Procurement and Construction (EPC) company. Structural steel is an important activity that both represents a significant portion of the overall project cost and is on the critical path. As a result, the outcome of the structural steel is an important determinant of overall project performance. The first section describes the original process and is followed by a description of how this process was re-engineered. The case study ends with an analysis of how the re-engineered process created potential transaction costs and how these were mitigated through the application of information technology and adaptation of the purchasing strategy

Original Engineering and Procurement Process

Figure 3 illustrates the organization, along with the process and information flows for the structural steel process prior to the reorganization.

The major activities involved are:

Layout: The overall facility layout determines the location and requirements of the structural steel. It includes, for example, the geometry of the facility and the placement of important equipment.

Design and Analysis: Based on the general layout the engineers determine the location and size of the structural members. In the next step, the engineers analyze that the steel members fulfill the load requirements, while minimizing cost and facilitating erection and fabrication. The resulting design drawings "should indicate the entire results of the structure: the type of the framing employed, the assumed loading, shears, moments, and other loads to be resisted by the members and their connections; and the type or types of steel to be used as well as where they should be used. " The design drawings should also specify the type of connection, but allow the fabricator flexibility of choice to obtain economic fabrication. [SS1]

Detailing: In the US and UK, the fabricator is, in general, responsible for detailing. This takes place either in house at the fabricator or the fabricator hires a detailing consultant "The shop drawings give all the information necessary for the fabrication of the component parts or elements of the structure – location, type, and size of all connectors; whether the connectors are to be installed in the shop or in the field." [SS2]

Fabrication: Upon reception of the complete plans and specifications, the fabricator can proceed to order the steel materials from the mill. The fabrication of the steel members and connection takes place in a fabrication site. If the fabricator is responsible for the detailing, the prints are sent to the designer for approval. Any corrections are made and the prints are then sent to the Engineer of Record (EOR) for approval and for an order to start fabrication. The contract between the EPC and the fabricator is complex and the price per ton differs depending on type and size of the steel members. As a basis for their bid, the fabricator has the drawings of an "equivalent" structure and estimates of the total volume. To bring down purchasing cost and limit price uncertainty, the EPC had entered in two long term multiple project agreements with some preferred structural steel projects. Nevertheless, in a market, in which steel prices are volatile and, lately, have been falling, a long-term contract often turned out to be more expensive than a project-based contract. As a result, the EPC often found it difficult to motivate the use of long terms contract to owners.

Erection: An erection crew is responsible for the erection of the members on the installation site. The EPC that was the subject of this study performed the erection through "direct hire" for a majority of the project. "Direct hire" implies that even though the crewmembers' contracts would be limited to the individual project, the EPC or one of its subsidiaries would hire them directly. The supervisors and all other non-manual employees would work directly for the EPC. The managers of the structural steel function claim that this arrangement substantially facilitates the incorporation of erection preferences, such as choice of connections, during the design phase. On some projects, the fabricator would be responsible for erection, and would then typically work with partner contractor.

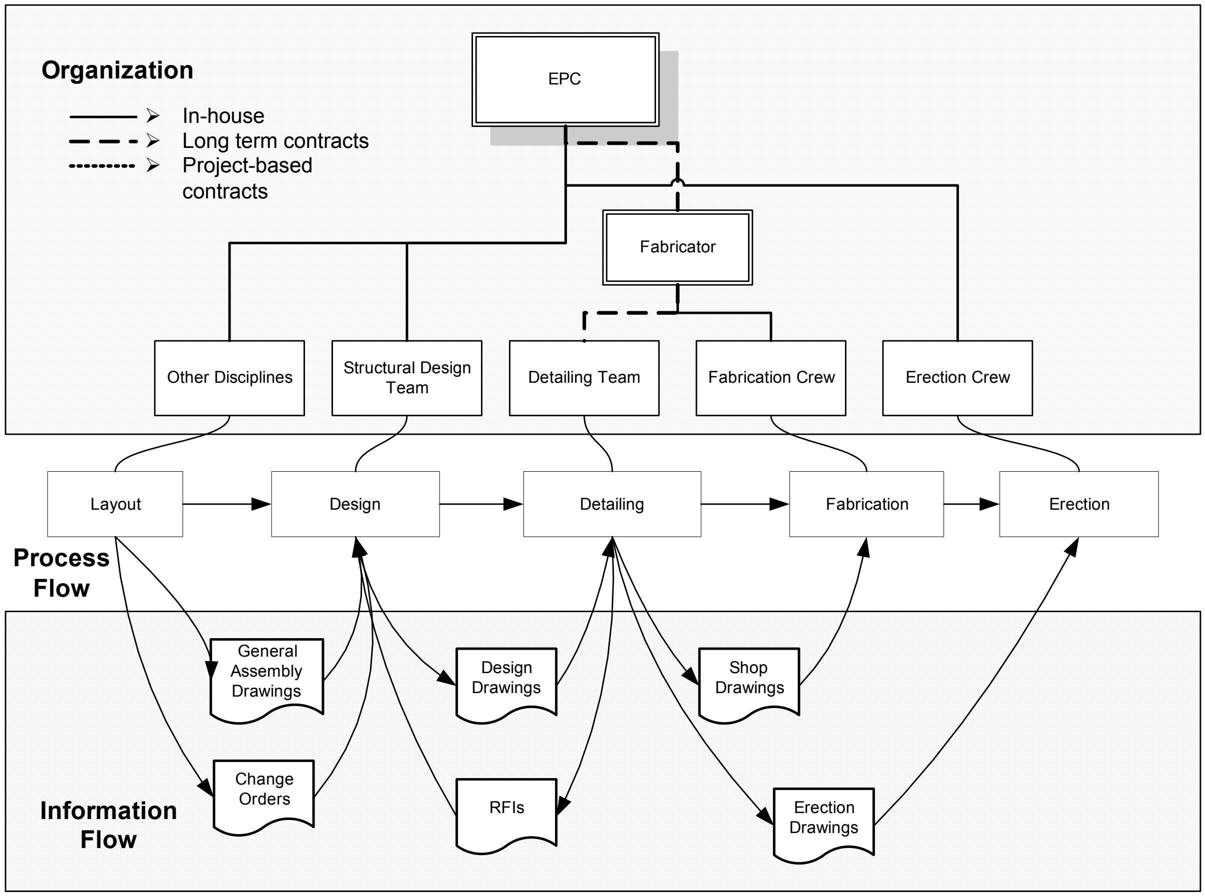

Figure 3 The organization, along with the process flows and information flows for the original process

The managers of the structural steel function within the various business units forms a continuing workshop. One activity of the workshop is to study the existing engineering and procurement process and identify opportunities for improvement. They found that the most important issues to address were:

Ownership of connections – Having the erection process in mind when detailing the components, can improve installation safety and efficiency in terms of cost as well as time. Given that the company does most of the erection in-house the managers identified improved integration of detailing erection as a prioritized area. The problem was that the fabricator who was responsible for the detailing was more concerned with its fabrication preferences than with the less familiar erection capabilities of the engineering/contractor.

Decreased lead times – Since structural steel is on the critical path any reduction in the completion time are important to the engineering/contractor but especially to the client who wants to start generating revenue from the completed facility as soon as possible.

Cost pressure – In a competitive and cost focus industry cost reduction is a major goal of all involved parties.

Re-engineered Process

This section provides a brief overview of the re-engineered section that will be discussed in more detailed in the below transaction cost analysis.

Figure 3 illustrated the re-engineered engineering and procurement process for structural steel. From an organizational or contractual perspective, the major change is that the fabricator is no longer responsible for the detailing, which is now done in-house by the engineering contractor or by a detailer hired directly by the contractor.

In terms of process flow, the detailing and design now, to a large extent, takes place in parallel. Concurrent engineering is well known to increase the amount of information exchanged between activities [Levitt].

However, as Figure 4 illustrates, most of the information flow is now in electronic format and integrated in to an object-based model. To improve the information flow the engineering contractor invested in a structural steel detailing software .The model-based software that is developed for design work on steel construction, and which provides 3D viewing and drawing solutions for fabricators and detailers. According to managers at the EPC the software fulfill two primary functions:

Automation: The software party automates part of the detailing work by automatically generating connections. There exist many generic connections but the user can also add customized rules to incorporate design, fabrication and erection preferences.. The same rule schema can then be employed to generate shop drawings. The remaining detailing thus becomes a matter of "cleaning up the shop drawings to a fabricator's preference in presentation style." Another advantage is that parts of the connection library can be reused on the same or the next project, which, naturally, saves time but also helps to enforce best practice.

Coordination: The project participants have real-time access to the same product model. The cost of coordination can then be mitigated by avoiding communication lead times, and rework. The models include links that facilitate data transfer with many 2D and 3D CAD systems, as well as structural design and analysis systems. It also automates the generation of paper based shop and erection drawings.

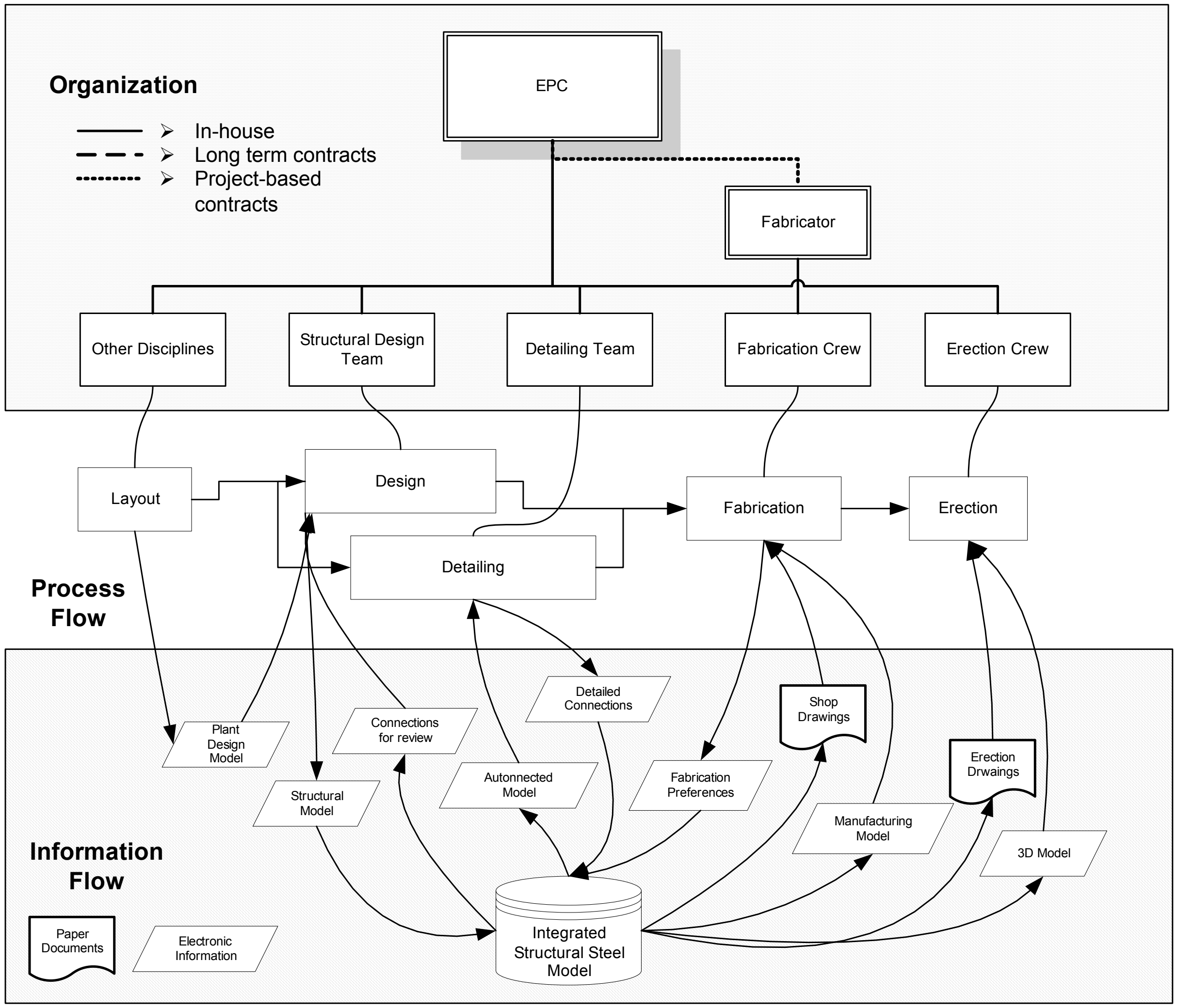

Figure 4 In the reengineered process the design and detailing are performed concurrently. The detailing now takes place in-house. The information flow is predominantly electronic and integrated into an object-based model.

After having described, the changes associated with the re-engineering project, we will, in the following section, discuss its impact on transaction costs.

Analysis of the case from a transaction cost perspective

This section analyzes the re-engineered process from a transaction cost perspective. The analysis is made from the perspective of the EPC, which is the organization driving the reengineering effort. The analysis will start with a description of how the business process was re-engineered to reduce the production cost of a project. The problem is that in the existing context, if both IT and purchasing strategies remain the same, increases in coordination costs and opportunism risks are likely to make the proposed changes unprofitable. However, it is also possible to see the organization's IT and purchasing strategy as enablers of a more efficient business process. The next sections therefore discuss how the company reduced the communication costs and mitigate the communication though the use of IT and changes in the contracting strategy.

Business Process Changes

The rationale for the re-engineering effort was to significantly reduce cost and schedule while ensuring quality. It is possible to divide this underlying goal into a set of concrete business objectives and actions as Table 1 shows. The achievement of each business objective requires a change in business process, and will result in tangible and measurable benefits that will reduce overall cost and schedule. At the same time, the changes can result in additional need for information exchange and thus increasing communication costs. Furthermore, a potential supplier that acts in bad faith will find himself or herself in a position of greater leverage, which, in turn, increases the risks of opportunism.

The reduction in the amount of labor required to complete the detailing was an important objective. To achieve this objective the contractor invested in the 3D model tool, which automated up to 70% of this work. The first order impact of the software is that it enables the automation of the detailing function. The target is to automatically generate 75% of the tertiary connections and 60% of the primary connections using the tool. Knowledge reuse can also be enhanced through the capturing of rules and definitions into a connection library, which "will continue to drive down cost over time." The detailing activity has changed into a matter of "scrubbing up" the automatically detailed design model. Another benefit was a reduction in the error rate as the work was automated. This change did not bring about any additional communication costs but did result in a potential opportunism risk. Since there was a substantial investment required before a detailer or fabricator could start using the model, a smaller company could be unable to recuperate the investment on a single project. The incremental investment needed was relatively limited: a software license cost $25,000 and a detailer required 10 days of training before being able to use the tool. On the other hand, if the detailer does have the underlying "IT competence that enables a swift move towards a model based process, the total required investment becomes substantially larger. As a result, if few other customers are currently using the tool, or require similar IT intensive services, the supplier may require a long-term contract before undertaking the necessary investments. From the EPC perspective, committing to model based detailing, can therefore limit the number of available detailers on future projects.

Another objective was to decrease the overall cost of detailing. One way to reach this goal is to shift labor-intensive work to low cost countries, which has been a common strategy of many US and European engineering and manufacturing companies. It is clear that, everything else equal, a lower cost of labor will reduce overall project cost. However, in the old paper based process the cost of communicating across distances and time zones were often substantial. In addition, multi-cultural differences, and the limits of international law, can potentially make it more difficult to prevent opportunistic supplier behavior through the design and enforcement of exhaustive contracts.

Starting detailing before design is completed offer the opportunity of achieving substantial schedule compression and was an important rationale for the reengineering effort. In this case, the engineering and construction contractor reengineered the overall process to make the design and detailing activates run more in parallel. Previously, the detailer waited until they received the complete design drawings before starting the detailing. In the new process, as the design of each work item is completed, the connections are generated and the baton is passed over to the detailing organization for "scrubbing –up". As experience increases, managers within the EPC predict that this activity can be minimized or even eliminated.

The problem is that it leads to a substantial increase in the amount of the information exchanged between the two activities. Any rework in the design activity now potentially has to be continuously communicated to the detailer. The integration of the two activities makes it more difficult to switch detailer, witch means that there is increased time specificity, and thus also a higher opportunism risk.

A different type of goal is to increase the competition among fabricators. Through project-based procurement the EPC can take advantage of the market situation in a volatile market. This approach can lead to increased communication costs, not only in terms of bid costs, but also because the information exchange has to be initialized for each project. The fabricators have individual preferences in terms of the design and format and shop drawings. Each organization will, for example, have its own conventions when it comes symbols, units, and names. Unless there exists a prior relationship between the engineering firm and the manufacturer, there are likely to exist some uncertainties and ambiguities that require communication. In an addition, a fabricator who is hired for the individual contractor is more likely to maximize short term profits through opportunistic behavior.

A final objective was to save time and enhance performance at the erection stage by incorporating erection preferences during detailing. One way to achieve this is to have the organization that undertakes the erection (often performed through direct-hire) to also take responsibility for the detailing. The problem is that if the fabricator is no longer responsible for detailing, it will be more difficult and costly to communicate fabrication preferences to the detailing function. The basic motivation for the fabricator to take responsibility for the detailing is to ensure the manufacturing preferences are taken into account at the detailing stage. The fabricator can, for example, have the equipment to fabricate clip angles of a certain dimension at low cost. The preferred clip angles could then be included in the detailed specifications whenever possible.

Table 1Business Process Engineering and the impact on transaction costs

Business Objective	**Changes in Business Process**	**Primary Benefits in terms of reduced production costs**	**Potential Communication Cost**	**Opportunism Risk**
More efficient Connection Design	Use Intelligent Model for Automatic Connection Designs	• Lower error rate in connection • Less labor required in detailing		OR1: Limited number of detailers that are willing and able to make required investments
Lower detailing cost	Outsource to Developing Countries	• Lower labor cost for detailing	CC1: Increased communication distance and cost	OR2: Cultural differences lead to potential contractual disputes
Compress schedule for design and detailing activities	Make design and detailing parallel	• Savings in overall project completion time	CC2: More coordination between detailing and design required	OR3: Increase in time specificity between detailing and design provides potential

				hold-up situation
Increase competition among fabricators	Procure fabricator competitively for each individual project	• Obtain best price for each project • Independence	CC3: Increased bidding and set-up costs, as well as interpretation uncertainty	OR4: Increased risk of short-sighted opportunistic behavior from fabricators
Improve coordination of detailing and erection	Shift responsibility for detailing to same organization that is responsible for erection	• Less errors identified during erection • Detailing connections and members to improve erection	CC4: Fabricator's preferences not taken into account in detailing	

This section presented the possible communication costs and opportunism risks that could be undesired consequences of the changes in business processes. The next section will analyze how the EPC aligned its IT and purchasing strategies to alleviate these potential problems.

Reduction of communication cost

Table 2 shows how information technology, in particular, can reduce the increases in communication costs that the new process can result in.

The increased coordination between design and detailing can primarily be counter-acted through the use of shared 3D model that allows changes to be communicated seamlessly and instantiations across disciplines. In addition the move towards formalized and predefined connection rules that can be reused can decrease uncertainty and thus the need for communication. The change in purchasing strategy also serves to reduce these costs. Having the same organization share responsibility for detailing and design reduces the need for formalizing information, and allows for efficient communication channels to develop over time.

The fact that the model is accessible in real time over the Internet makes the communication cost independent of geography and hence counteracts the increase in communication costs that overseas detailing could otherwise lead to.

The software also allows for the production of customized shop drawings, which facilitates the cost of communicating with a new fabricator. In addition, drawings that are model-based are more likely to be complete and have missing or ambiguous information. Finally, the software allows the fabricator to upload their manufacturing preferences. These preferences are often not very complex and, in general stable, over time. A fabricator could therefore enter them into a file that can be uploaded into the detailing software. This feature ensures that the detailing take into the manufacturers equipment and cost structure.

Table 2 Mitigation of communication costs through IT and contracting strategies

Potential increases in communication cost	**Risk Mitigation through IT deployment**	**Cost reduction through adaptation of contract strategy**
CC1: Outsourcing across borders increase communication distance and cost	Model is accessible in real time across the Internet	
CC2: Increase coordination between detailing and design	Shared 3D model reduces cost and time of coordination	Integration of detailing reduces the need to formalize the exchange
CC3: Increased bidding, set-up and misinterpretation costs as new fabricator misinterprets shop drawings	Possible to customize format of shop drawings to the preferences of each fabricator	
CC4: Fabricator's production preferences lacking not communicated to detailing	Fabricator's production preferences can be uploaded prior to detailing	

Table 2 shows that the EPC leveraged IT as the predominant strategy to reduce communication costs.

Mitigation of Opportunism Risks

While the communication cost could be reduced mainly through the deployment of information technology, changes in the purchasing strategy were instrumental as a means to reduce opportunism costs (Table 3). The most straightforward way to ensure that the detailing organization invests in software licenses and user training is through vertical integration. The engineering contractor, now performs about 50% of its detailing in-house and can thus leverage the investment across multiple projects. It also works closely with a few selected detailers, who are hired at an hourly rate rather than a fixed price bases. A detailer that is paid on a cost plus bases and who cherishes the opportunity to obtain future contracts, is unlikely to take advantage of the increased uncertainty and time specificity of the new process to "hold-up" the contractor. In this context, the design and pricing of the software also serves to mitigate risks. The EOR has also invested in the formalization of its preferences and activities so that these can be now be embedded into the tool. This limits the start-up cost for a new detailer by minimizing the required relationship specific investments.

For other project participants, such as designers and project managers, there are viewer and project management that enable them to take advantage of the IT tool without making substantial investments.

The integration of detailing also serves to mitigate the additional uncertainty that arise from moving detailing abroad. By separating detailing and fabrication the engineering and construction company can reduce the uncertainty and the complexity of the information that is exchanged in between different companies. It would be very difficult to prevent opportunistic behavior through contracts if detailing services were procured on a competitive basis from a different country. The in-house detailing team can also learn to interpret the EPC's preferences in terms of expectations and presentation of information, as they continuously work on different projects. At the same time, automation both reduces the scope of the detailing task itself, and serves to formalize the process. Both of these changes can help to lessen the complexity of the information that has to be exchanged across cultural borders.

To counter the risk that a fabricator that is hired on a project basis acts opportunistically both purchasing and IT strategies constitute important enablers. By moving detailing out of the fabricator's scope of work, complexity can be reduced substantially. In addition, shop drawings that are based on a complete product model are likely to contain less uncertainties, errors and items that are subject to interpretation. Opportunism risks are also reduced since the EOR is now in control of the detailed shop drawings "which will enable to hire a new or replacement fabricator at short notice, wherever shop availability exists."

Table 3 Mitigation of opportunism risk through IT and contracting strategies

Opportunism Risk	Risk Mitigation through IT deployment	Mitigation through purchasing strategy adoptions
OR1: Unwillingness or inability of detailers to invest in software limits competition	Free viewer and low cost project management licenses for project members Incorporation of EPC' in model preferences limits relationship specific investments.	Integrate Detailing Enter into partnerships with detailers
OR2: Contract uncertainty in multi-national context	Reduced complexity of detailing reduces communication needs.	Integrate detailing
OR3: Fabricator takes advantage of increased time specificity of detailing		Detailing removed from fabricator's scope of work and performed in-house
OR4: Opportunistic behavior from fabricator that is procured on a project basis	Software provides complete shop drawings to Fabricator	Reduce uncertainty by moving detailing out of fabricator's responsibility.

As shown in Table 3, neither IT nor purchasing strategy was sufficient to by itself mitigate the opportunism risks. Instead, the EPC aligned both of these strategies to generate process that was effective in an overall perspective.

4. Discussion

This article presents a new framework to analyze the impact of information technology and purchasing strategy on the construction industry. The case study illustrates that the re-engineering of business process would not be possible without information technology deployment and the adaptation of the purchasing strategy, since these serve to mitigate potential increases in transaction costs that would otherwise occur. The framework links the abstract transaction cost economic view with the more hands-on business process re-engineering approach.

Table 4Summary of strategic actions and their impact on business objects and transaction costs

		Business Objectives			Transaction Costs	
Change	Classification of changes	Cost	Time	Quality	Communication Cost	Opportunism Risk
Concurrent Detailing and Design	Sequencing		+++	+	--	- -
Project-based Contracting of	Purchasing	++				- -

Fabrication						
Detailing in Low Cost Country	Location	++			- -	- -
Invest in 3D Model	Information Technology		+	+	+	-+
In-house Detailing	Purchasing				++	++

Table 4 summarizes the strategic actions taken in the re-engineering project and their impact on business objectives and transaction costs. In the summary we have classified the actions in terms of their primary impact areas. The Table shows that while the changes in the sequencing and location of activities directly support the primary business objectives, they also bring about substantial transactions costs. For the changes in purchasing and information technology strategies, the result is more mixed. While one of the changes purchasing strategy serve to mitigate transaction costs, the other (project-based contracting of fabrication) could potentially increase them. Similarly, the IT investment supports cost reduction through automation, while it at the same time reduces communication costs, and both increases and mitigates opportunism risks. Both IT and purchasing could in themselves be deployed to save costs, but their primary function was to mitigate potential transaction costs. The alignment of IT and purchasing strategies enabled the contractor to re-organize its activities in a more efficient manner. The result was improvements in terms of cost, schedule, and quality, which could be achieved in the absence of higher transaction costs.

This research has important implications for researchers as well as industry practitioners. From an academic perspective, the case study illustrated the complexity associated with the re-engineering of business processes in the construction industry. It provides a detailed analysis of the different process changes along, with the related IT investments and adaptation of the contracting strategy. This analysis also shows that transaction cost economics is a useful framework to support the analysis of this type re-engineering projects in AEC, as it can help to explain the underlying relationships.

The case study illustrated that in the construction industry, in which multiple organizations work on the same product, schedule reduction is a major opportunity but also a challenge. Information technology investments are often not sufficient to overcome the increased transaction costs that occur when activities become more dependent as they are carried out in parallel.

From a transaction cost perspective, another important lesson learnt is that the scope of work that each party undertakes is a variable rather than a constant. By separating detailing from fabrication, the engineering contractor was able to move towards more competitive procurement. The concurrent engineering increases the time specificity and thus makes competitive procurement of fabrication and detailing unfeasible. Nevertheless, the increase in interdependence and time specificity were mostly related to the detailing. The EPC could therefore, by separating the detailing from the fabrication, reduce the time specificity of the fabrication, which could therefore be awarded on a competitive basis. The shift was facilitated by the reduction in uncertainty and communication cost achieved through the use of a 3D model.

This study also opens several interesting avenues for future academic work.

First of all, to investigate the generality of the findings, the study should be repeated in other settings, involving different companies, trades, and types IT investments. From a global perspective, there is also likely to be substantial variation between the different regions of the world.

Another important next step is to quantify the transaction costs. Several studies have developed measures for industries other than construction [TC paper quotes], using subjective surveys, and it would be interesting to repeat this research in AEC. A more ambitious, although interesting, effort would involve the quantification of transaction costs in monetary terms.

Quantification can also serve as a facilitator for simulation, which constitutes another avenue for future research. By simulating the behavior of the participants in the construction supply chain, researchers can enhance their understanding of how different types of IT investments are likely to impact the market structure. We believe that the study described in this paper helps to determine the important relationships that a simulation model should comprise.

Moreover, this analysis has not considered the social consequences of the re-engineering effort. For example, the incorporation of the fabricators' preferences into the model required face-to-face meetings at an early stage. Team members observed that these meetings helped contributed to the generation of team spirit and trust, ad thus helped to mitigate the risk of opportunism. Given that the construction industry is often described as a “people business,” further investigation of the social impact of BPR and IT deployment is another future area of research.

Also industry decision-makers can draw conclusions from this study. First and foremost, it shows that information technology investments cannot be considered in isolation of a construction company’s overall business processes and supply chain. Information technology does no longer automate isolate applications, but will impact other functions, as well as transaction partners. The result is not only increased complexity and risk, but also substantial opportunities. It is therefore crucial that the change process involve not only the IT function, but also all concerned stakeholders. Furthermore, information technology is an important enabler of business process reengineering, but that it cannot by itself mitigate all the costs that can arise. Purchasing strategy and IT strategy should be viewed in tandem. The study showed, that information technology enabled the EPC to vertically integrate (change of purchasing strategy) in a cost efficient manner. The vertical integration enabled the EPC to undertake to important changes without taking on a greater transaction risk. These are 1) the re-organization of design activities to increase efficiency, 2) and increasing competition among fabricators. For industry professionals, this is an illustrative example of how the careful alignment of IT and purchasing strategies can be leveraged for increased competitiveness in construction. IT is no longer a matter of achieving cost savings by automating isolated processes but an enabler of change, which has to be integrated with the internal organization, as well as the external supply chain.

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