An Empirical Study Relating Construction Firm Performance and IT Utilization

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Summary

This paper examines the impact of information technology (IT) utilization on construction firm performance. Based on empirical data collected from 74 US construction firms, the analyses provide evidence that IT has a positive impact on overall firm performance, schedule performance, and cost performance. Firm performance is a composite score of several metrics of performance: schedule performance, cost performance, customer satisfaction, safety performance, and profit. No relationship is found between IT utilization and customer satisfaction, safety, or profit, although this may be due to limitations of the study given strong correlations between IT utilization and cost and schedule performnance. The empirical evidence of positive association between performance and IT use provided by this research is significant to both construction practice and research literature. This evidence should encourage firms to adopt and invest in IT tools.

1 Introduction

This paper examines the impact of information technology (IT) utilization on construction firm performance. While several authors have had promoted long-held visions for computer-integrated construction, to-date there have only been limited studies about construction firms' adoption of IT and even fewer studies concerning the impact of IT on firm performance. Indeed, the construction industry has been described as "hesitant" in its adoption of IT tools (Andresen et al. 2000). Mitropoulos and Tatum (2000) suggest two major reasons for reluctance to incorporate technology: Uncertain competitive advantage from using new technologies and lack of information regarding technologies and benefits. Correspondingly, construction researchers have called for improved tools to analyze how technology affects the performance of the firm. Hampson and Tatum (1997) argue that managers need a way to measure the expected benefits of IT to invest in technology. O'Connor and Yang (2003) call for quantitative analysis to guide IT implementations, arguing that firms would be better able to make technology decisions in the existence of such quantitative analysis.

This research responds to these calls by examining the relationship between firm performance and IT utilization. Based on empirical data collected form 74 construction firms, this research conducts regression analysis to test the relationship between firm performance and IT utilization (as opposed to IT investment). Six hypotheses are tested using eight regression models. The regression models indicate that there is a strong positive correlation between composite metrics of firm performance, as well as between cost and schedule performance. However, some performance measures (safety, customer satisfaction, and profit) show no relation between performance, contradicting some current case study observations. The results help focus areas for future research.

2 LITERATURE REVIEW

There are relatively few studies of the impact of IT on performance, and those studies that exist focus on project as opposed to firm performance. Further, many of the studies focus on the impact of specific technologies (3D/4D CAD and supporting technologies in particular). For example, Griffis et al. (1995) studied the impact of 3D CAD on project performance in terms of cost (actual cost/estimated cost), schedule (actual schedule/estimated schedule), and rework (additional labor expenditure due to rework/total labor expenditure of the project). For a sample of 93 projects, Griffis et al. (1995) concluded that projects using 3D model experience 5% reduction in cost growth, 4% reduction in schedule slip, and 65% reduction in rework. Fischer and his colleagues (Fischer et al (2003); Koo and Fischer (2000)) have conducted a number of case studies on the impact of 4D CAD on project performance. Koo and Fischer (2000) argue that their case study demonstrates the usefulness of 4D models in visualizing and interpreting the construction sequence, conveying special constraints of a project, formalizing design and construction information, anticipating safety hazard situations, allocating resources and equipment relative to site work place, and running constructability reviews. This visualization, according to Fischer et al. (2003), allows more project stakeholders to understand the construction schedule quickly and completely compared to the traditional construction management tools.

The studies briefly reviewed above relate to specific technologies as opposed to benefits gleaned from adoption of a broader range of technologies. However, a related stream of research attempts to assess the broad level of IT utilization on projects. For example, building from the IT-Barometer survey developed by Samuelson (2002), Rivard (2000) assessed the level of IT utilization across design and construction firms in Canada. He found the majority of firms were using computers heavily in administrative tasks such as book keeping, although fewer firms use IT tools for project management tasks or for electronic document exchange. A recent meta-study of related industry and academic studies by Kumar (2003) reports similar results, finding wide-spread use of basic IT tools for accounting, word-processing, spreadsheets, and e-mail. A minority of firms have used more advanced tools such as 3D models, although Kumar (2003) reports that there is increasing utilization of tools such as project web-sites (particularly among larger firms).

Studies such as those reported on by Kumar (2003) provide a useful albeit broad snapshot of industry adoption of IT. To gain a more detailed view, O'Connor et al. (2000) conducted a study of IT utilization for specific tasks on projects. The authors divided the project life cycle into six phases: front end, design, procurement, construction management, construction execution, and startup/operations/maintenance. Each phase is comprised of work functions. Examples of the procurement phase work functions include: determine the lead time required to order equipment and materials, conduct a quantity survey of drawings, and link quantity survey data to the cost estimating process. The total number of work functions in a project is 68.

O'Connor et al. (2000) used a survey questionnaire to collect the data. The survey was administered to owners, architects/engineers, contractors, design/build firms, engineering/ procurement/construction firms, and construction management firms. Data was collected for 180 projects. For each subject project, the survey asked participants to assess the degree of technology used in executing each work function for that project by choosing one of three levels. Level 1 used no electronic tools wheras level 3 utilized heavily automated and/or integrated functions. (Examples of the levels are given in the Appendix.) The study utilizes a scoring system to quantify the degree of technology use for the project at hand. The final score reflects the levels of technology use on all work functions. O'Connor et al. (2000) report that on a 0 to 10 scale, the US construction industry scored 3.85, indicating a relatively low level of overall usage of technology.

In a follow-up study, O'Connor and Yang (2003) investigated whether project success is associated with level of technology use. Project success is assessed in terms of cost performance and schedule performance. O'Connor and Yang's (2003) analyses indicate that technology utilization may make significant contribution to project cost and schedule performance, although their study is limited to comparison of populations. Hence the degree to which technology use drives performance is not quantified.

3 RESEARCH QUESTIONS & METHODOLOGY

The current literature indicates a positive relationship between IT utilization and project performance. However, there is only limited evidence of the degree to which IT makes an impact (i.e., O'Connor & Yang (2003)). Moreover, none of this research tests the degree to which IT utilization affects the performance of the firm. Certainly, the notion of project and firm performance are related. If a project utilizes IT to improve performance, then it is reasonable to infer that the firms involved on a project should also benefit. The difficulty is that it is unclear to which firms the benefits of IT accrue. If, for example, project cost is reduced, do the cost savings accrue to the owner, the contractor, or the subcontractors? Hence, in an attempt to assess the benefits of IT (and, in turn, guide investment decisions), it is important that firms' managers understand the impact on their firm. Thus the basic research question addressed by this study is: "Does IT utilization affect firm performance?" The researchers address this question by statistical methods, obtaining data about IT utilization and firm performance and seeking to determine a relation, if any. Linear regression is used to investigate the relationship between the variables. The sample population is limited to construction firms.

Given the reported prevalence of IT use for basic accounting and related tasks, it is perhaps most useful to investigate the impact of IT utilization for project operations as opposed to back office tasks. Hence, the researchers limited their investigation to project activities. As O'Connor et al. (2000) have validated use of an extensive research survey to determine IT utilization on project work functions, a choice was made to assume their instrument with as few changes as possible. For this research, the work function sets for the procurement, construction management, construction execution, and start-up phases were adopted directly from O'Connor et al. This provides 48 work functions for participants to evaluate. (See the Appendix for illustrative details of he survey instrument.) Participants were asked to rate their firm's level of IT use across projects, following the level 1, 2, 3 rankings of O'Connor et al. (2000).

The aggregate level of technology utilization for a firm is called the ITindex and is rated on a (0-10) scale. The ITindex is calculated as follows (O'Connor et al 2000):

ITindex = [[Sum of work functions scores / (Total # of work functions

*- # of "N/A" responses - # of "Don't know" responses)] - 1] * 5* (1)

The ITindex score for each firm is used for the independent variable in the regression. As the population for the study is comprised of construction firms, O'Connor et al's (2000) front end and design phases were excluded. While some design build firms may participate in the early project stages, it was felt that the limiting the survey to construction phases would allow for the most consistency when employing IT utilization as the independent variable.

The independent variable for regression is firm performance. A review of the related benchmarking literature (Fisher et al. (1995), CBPP (1998), Hudson (1997), CII (2000)) suggests the following metrics: Schedule performance, cost performance, customer satisfaction, safety performance, and profit. Definitions for these measures are shown in Table 1.

Metric (1)	Method of measurement (2)
Schedule performance	% of the time projects are delivered on/ahead of schedule
Cost performance	% of the time projects are delivered on/under budget
Customer satisfaction	% of repeat business customers
Safety Performance	Experience Modification Rating (EMR)
Profit	Net profit after tax as a % of total sales

Table 1: Metrics of performance comprising compo firm performance

Respondents were asked to rate their firms performance for each metric. A regression can be run for each metric individually. It is also possible to determine a composite score of the metrics to gain a rating for firm performance. This composite score was determined using Data Envelopment Analysis (DEA) (Cooper et al. (2000)). DEA is a non-parametric statistical technique based on linear programming. It enables firms to assess their relative performance compared to other firms in the industry. Using DEA terminology, the best performance firms form an efficient frontier. It is then possible to measure the performance of the remaining firms against this frontier. DEA analysis scores the performance of each firm based on a (0-1) scale.

Collection of multiple metrics for the independent variable enabled the researchers to test six hypotheses: That each of the five individual metrics and the composite firms performance is positively correlated with IT utilization. Each hypothesis is shown in Table 2.

No. (1)	Hypothesis (2)
1	ITindex and firm performance are positively correlated
2	ITindex and schedule performance are positively correlated
3	ITindex and cost performance are positively correlated
4	ITindex and customer satisfaction are positively correlated
5	ITindex and EMR are positively correlated
6	ITindex and profit are positively correlated

Table 2: Research hypotheses

4 DATA COLLECTION, DESCRIPTIVE STATISTICS, AND CONSTRUCT VALIDITY

4.1 Data Collection

Data collection for the survey was conducted through a web-based survey in Summer 2003. Respondents were asked to provide information regarding firm performance metrics (Table 1) and to rate the level of IT utilization for each of the 48 work functions. Additional information was collected about respondent job information and general data about the respondent's firm, including annual revenue, industry sector, and type. The survey questionnaire was posted on the University of Florida web site. The survey link was e-mailed to 777 construction industry practitioners identified from alumni of the University's Department of Civil & Coastal Engineering and the M.E. Rinker, Sr. School of Building Construction. 232 e-mails returned back as undeliverable. Of the 545 deliverable e-mails, the researcher received back 88 responses, which accounts for a 16.15% response rate. The 88 respondents represent 74 firms.

4.2 Descriptive Statistics

The managerial level of the 88 respondents is broadly distributed, although there is a preponderance of responses from senior positions. Fifty two percent are from top management (i.e., president, vice president, CEO), twenty-eight percent are from middle management (i.e., director of certain unit within the organization, senior manager, project manager), and 13% are from low management level (i.e., field manager, assistant project manager, project engineer). Seven percent of the respondents fill positions that do not indicate managerial responsibilities (i.e., estimator, IT specialist, cost engineer).

Among the 74 firms, 31 firms (43%) are general contractors (GC), 7 firms (10%) are construction managers (CM), 21 firms (29%) are both GCs and CMs, 3 firms (4%) are design-build (DB) firms, 2 firms (3%) are subcontractors, 4 firms (5%) are GCs, CMs, and D/B firms, and 6 firms (6%) have other combinations. Across industry sectors, 7% are residential, 31% are commercial, 4% are industrial, 4% are highway and heavy, 8% are residential and commercial, 23% are commercial and industrial, 12% are residential, commercial, and industrial, and 11% have other industry sector combinations. With regard to revenue, 50% of the firms are over $50 million revenue, 18% are in the range of $(25-50) million, 23% are in the range of $(5-25) million, 8% are in the range of $(1-5) million, and 1% are less than $1 million in revenue.

Firm revenue (1)	**Number of firms (2)**	**ITindex**					
		Mean (3)	**Sd* (4)**	**Min. (5)**	**Max. (6)**	**25th Quartile (7)**	**75th Quartile (8)**
<$1 million	1	1.92	--	--	--	--	--
$(1-5) million	6	2.524	0.972	1.061	3.83	1.946	3.478
$(5-25) million	15	3.83	1.391	1.143	6.609	2.679	4.211
$(25-50) million	12	3.499	1.501	1.064	6.667	2.336	4.203
> $50 million	35	4.277	1.708	0.897	8.205	2.88	5.119
All	69	3.761	1.63	0.897	8.205	2.411	4.785

*Standard deviation

Table 3: ITindex descriptive statistics

Table 3 provides ITindex descriptive statistics by firm size and for all sizes combined. Following O'Connor et al. (2000) in ensuring that the response data is adequate to be representative, a minimum response rate of 70% of work functions is applied. Acceptable work function assessments included any of the three technology level responses (1-2-3) or the N/A response. In other words, the number of responses on the 1, 2, and 3 levels, and N/A responses divided by the total number of work functions should be equal to, or exceed, 70%. Five firms did not pass the 70% response rate. This leaves the number of firms with a calculated ITindex at 69. The ITindex mean for all firms combined is 3.761 with a standard deviation of 1.63. The minimum and the maximum values of ITindex are 0.897 and 8.205 respectively. Table 4 further shows both the 25th and 75th quartiles of the ITindex. For all firms combined, the 25th and 75th quartiles are 2.411 and 4.785 respectively. The 25th quartile indicates that 25% of the firms have an ITindex of less than 2.411. The 75th quartile, on the other hand, shows that 25% of the firms have an ITindex of more than 4.785.

After completing the objective rating section of the survey, respondents were asked to subjectively report their beliefs about the impact of IT on performance for firm profitability, schedule performance, cost performance, customer satisfaction, and safety. Results for this belief as detailed in Table 4.

IT has a positive impact on: (1)	Strongly disagree (2)	Slightly disagree (3)	Slightly agree (4)	Strongly agree (5)	No response (6)
Firm's profitability	48	41	2	1	8
Schedule performance	43	39	9	2	7
Cost performance	38	44	9	2	7
Customer satisfaction	26	55	11	1	7
Safety performance	8	52	25	7	8

Table 4: Respondents' beliefs of the impact of IT on performance (%)

5 Analysis and Test of Hypotheses

Regression analysis was used to investigate the six hypotheses that IT has positive impact on firm performance (see table 2). Table 5 summarizes the regression models investigated. For all regression models, ITindex is the sole explanatory variable. Note that the first hypothesis regarding firm performance is investigated using the first three models of table 5 (SCCP, SCCE, SC) that reflect composite scores calculated using DEA. In addition to the three regression models for composite or firm performance metrics, there are five regression models for individual performance metrics (e.g., models for cost, schedule, safety, customer satisfaction, and profit). Table 5 also shows the number of firms that are included in each model. Missing data restricted the number of firms that could be included in composite scores.

Model no. (1)	Dependent variable (2)	Explanatory variable (3)	Number of firms (4)
1	SCCP score SCCP is a composite score of schedule performance, cost performance, customer satisfaction, and profit	ITindex	47
2	SCCE score SCCE is a composite score of schedule performance, cost performance, customer satisfaction, and EMR		34
3	SC score SC is a composite score of schedule performance and cost performance		46
4	Schedule Performance (%)		64
5	Cost Performance (%)		64
6	Customer Satisfaction (%)		64
7	Profit		
8	EMR		

Table 5: Regression models

For each of the regression models, eight indicator variables are used to distinguish firms depending on their revenue size and type of construction. Two indicator variables are used for revenue size: "Small" and "Midsize." The "Small" indicator variable refers to firms of revenue size $(1-5) million. The "Midsize" indicator variable refers to firms with revenue size that ranges between $5 million and $50 million. Five indicator variables are used for type of construction as detailed in Table 7. These indicator variables are: Residential (R), Commercial (C), Industrial (I), Highway & heavy (H), and Subcontractor (S).

Sample scatterplots and regression lines are shown for the SCCP and SCCE scores and ITindex (figures 1 and 2). Table 6 summarizes the regression equation and R-squared value for each model. Models 1-5 show strong positive correlation between IT utilization and performance (R2 of 0.35 at a low to 0.48 at a high for the composite metric SC). As there are many contributing factors to performance, the researchers believe that explanatory power of 35 to 48 percent is quite strong. Note that for models 1-5, the F and t tests show significance with p-values conservatively set at 0.05. (Further discussion of standardized residuals and goodness of fit can be found in El-Mashaleh (2003).) Models 6-8 show no correlation.

The indicator variables do not show any significant differences among the population based on size or industry. For example, for the SCCE model (table 6), the regression equation shows that for every 1 unit increase in ITindex, holding the residential variable fixed, there is 1.76% increase in the SCCE score. Residential contractors have 11% lower SCCE score when compared to the rest of the contractors. However, such a relationship is not consistent across all models for any of the size or industry variables. In general, we can conclude that the positive relationship for models 1-5 is consistent for all types.

Model no. (1)	**Dependent variable (2)**	**Form (3)**	**R2 (%) (4)**
1	SCCP score	SCCP score = 0.785 + 0.0241 ITindex + 0.0758 Commercial	35.5
2	SCCE score	SCCE score = 0.893 + 0.0176 ITindex - 0.110 Residential	36.1
3	SC score	SC score = 0.714 + 0.0205 ITindex + 0.0603 Midsize - 0.0772 Residential + 0.112 Commercial + 0.0912 Highway&heavy	48.5
4	Schedule Performance	Schedule Performance = 54.9 + 5.13 ITindex + 16.2 Commercial - 11.8 Industrial	35.4
5	Cost Performance	Cost Performance = 70.2 + 2.95 ITindex + 16.1 Small + 10.4 Midsize - 7.49 Residential - 15.9 Highway&heavy	37.7
6	Customer Satisfaction	Not significant	NA
7	Profit		
8	EMR		

Table 6: Summary table for regression analysis of ITindex and performance

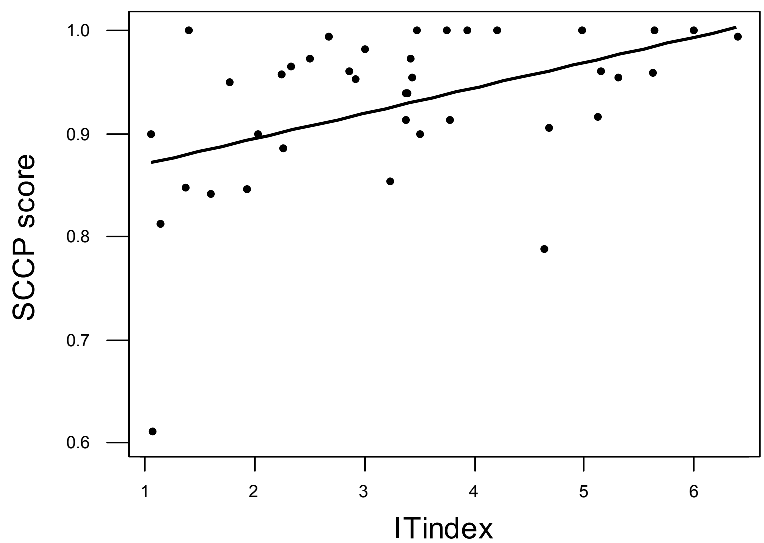

Figure 1: Regression plot for SCCP score and ITindex

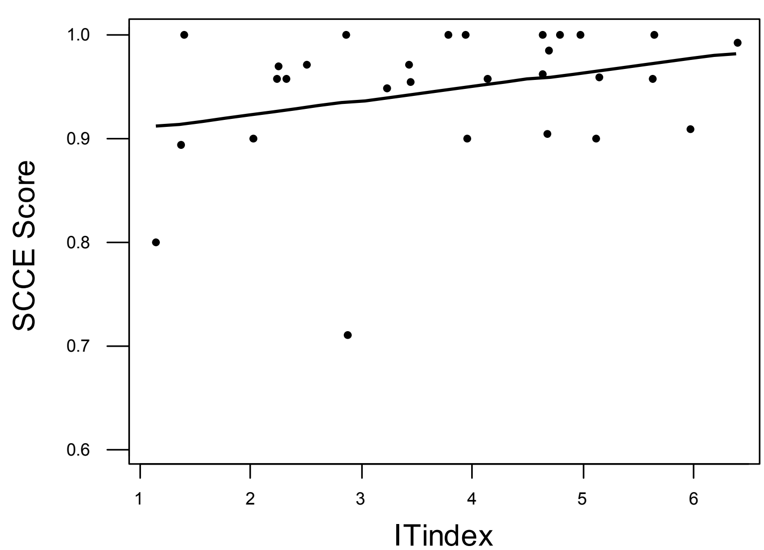

Figure 2: Regression plot for SCCE score and ITindex

6 DISCUSSION

In summary, the regression results show a significant positive relationship between firm performance for three composite metrics of firm performance, as well as a significant positive relationship between cost and schedule performance. No relationship was found for profitability, safety performance as defined by EMR, or customer satisfaction. Table 7 summarizes the research hypotheses and indicates whether they are supported by the empirical analysis or not. The first three research hypotheses are supported by the empirical analysis while the last three research hypotheses are not supported.

No. (1)	**Hypothesis** (2)	**Supported/ Not supported** (3)
1	ITindex and firm performance are positively correlated	Supported
2	ITindex and schedule performance are positively correlated	Supported
3	ITindex and cost performance are positively correlated	Supported
4	ITindex and customer satisfaction are positively correlated	Not supported
5	ITindex and EMR are positively correlated	Not supported
6	ITindex and profit are positively correlated	Not supported

Table 7: Research hypotheses that are supported/not supported by the empirical analysis

The empirical analysis results make an interesting comparison to the belief of the participants reported in Table 4. In general, the majority of respondents strongly or slightly agreed that IT has a positive impact on all performance measures, with the strongest beliefs (as measured by strongly agreed responses). For schedule performance and cost performance, the regression results support the perceptions of the respondents. Eighty two percent of the respondents believe that IT has a positive impact on schedule performance and cost performance. These perceptions are strongly supported by the data.

The belief by 81% of the respondents that IT has a positive impact on customer satisfaction is not supported by the empirical analysis. The regression results show no significant relationship between IT and customer satisfaction. A possible explanation is that IT and customer satisfaction have positive limited association that is not significant enough to show up on the data. It is expected that customers are more satisfied with the use of the technology that provides to them easier access to project data (e.g., contract and document control) and allows them to perform real-time collaboration (e.g., project web sites, web conferencing) with all project parties. Further, some technologies are owner driven. Mitropolous and Tatum (2000) identify owners as a force that motivates contractors to adopt IT. It is therefore expected to see happier customers with the adoption of IT tools that are driven by them. Such owner driven adoption may not be captured in the survey and is an area for substantive case examination.

Regression analysis shows no association between safety performance (EMR) and IT. This contradict previous research that indicates IT can help increase safety awareness. For example, the use of digital cameras helps to detect safety violations for corrective action by management. Koo and Fischer (2000) argue that the use of 4D helps to anticipate safety hazard situations. Fischer et al. (2003) report that participants of a workshop hosted by Walt Disney Imagineering (WDI) and Center of Integrated Facility Engineering (CIFE) at Stanford University in 1999 identify increased site safety as one of the benefits of 3D and 4D use. It is possible that EMR, while readily available as a measure, is not the best metric for analysis. EMR is based on historical performance, and hence recent improvements in safety due to use of IT may not be reflected in the current measure.

While 89% of the respondents believe that IT has a positive impact on profit, the regression analysis does not reveal any association between the two variables. This is surprising as there is a strong correlation between cost and schedule performance and IT utilization. There are four possible explanations: First, there is no relaitonship. Second, there may be noise in the data. Third, benefits passed to other project stakeholders (i.e., owners, subs, etc.). Fourth, the cost of the technology reduces the profit. The research does not provide answers to these questions. This leaves the relationship between IT and profit open for further examination.

For all measures, the research does not address the lag effect of IT. As IT implementation can take time to impact performance, and as most firms are still early in their adoption, it is possible that the positive (or negative) results of IT utilization are not fully reflected in the survey data. This can partially explain why some construction firms with high levels of technology are not enjoying a high performance position. Further research with IT utilization and performance data over several years needs to be conducted and is a logical next step for the researchers.

7 CONCLUSIONS

To the authors' knowledge, this research is the first quantitative assessment of the impact of IT on construction firm performance across several metrics. Based on data collected from 74 construction firms, this paper provides empirical evidence that IT has a positive impact on performance. For every 1 unit increase in ITindex, there is a positive increase in firm performance, schedule performance, and cost performance. Firm performance measures used in this study are composite scores of several metrics of performance: schedule performance, cost performance, customer satisfaction, EMR, and profit. No correlation was found between safety, customer satisfaction, or profitability. However, the survey results are not necessarily conclusive. The strong correlation between cost and schedule performance and IT utilization indicates positive benefits that we may expect to carry over to other areas. It is plausible that limitations in the survey instrument and/or lags in observing benefits may correspond to the lack of correlation between some performance metrics and IT utilization.

Overall, the research presented in this paper can be considered a snapshot of firms' current IT utilization and performance. As firms learn to better incorporate IT into their work tasks, benefits will likely become clearer and the evidence stronger. Hence, the evidence suggests to a hesitant construction industry (Mitropoulos and Tatum (2000), Andresen et al. (2000)) that IT does have benefits and should encourage firms to adopt and invest in IT.

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Appendix

While the survey instrument is to lengthy to present in this short paper, illustrative details are presented below. Table X shows a sample of the 48 work functions investigated while Table Y indicates the guidance given to survey particpants to help them calibrate their responses. As noted, these functions draw from O’Connor et al.’s (2000) research.

ID	Task	Degree of Technology Use				
Procurement Phase		**Don't know**	**1**	**2**	**3**	**NA**
1	Determine the lead time required to order equipment and materials					
2	Conduct a quantity survey of drawings					
3	Link quantity survey data to the cost estimating process					
4	Link supplier cost quotes to the cost estimating process					
5	Refine the preliminary budget estimate					
6	Develop the milestone schedule					
7	Develop and transmit requests for proposal to suppliers and subs					
8	Prepare and submit shop drawings					
9	Acquire and review shop drawings; send response					
10	Compile quotes from suppliers and subs into a bid or proposal package					
11	Monitor the progress of fabricators					
12	Plan the transportation routes of large items from the fabricator to the job site					

Table 8: Sample work functions in survey instrument

Degree of Technology Use	Level 1	Level 2	Level 3
Characteristics	No electronic tools or commonly used electronic tools	Specialized, stand-alone electronic tools	Integrated electronic tools
	Hand written data	Data in electronic format	Shared electronic data (e.g. network)
	Verbal or paper data transfer/little or no re-use of data	Electronic data entered numerous times	Single entry of data/re-cycling of data
	Human to human		Machine to machine
	Proximity important to information transfer		Proximity is irrelevant
Example 1 Bid proposal	▪ Get paper copies of drawings/specs ▪ Input of prices in a spreadsheet ▪ Hand a hard copy of proposal to owner	▪ Get CD-ROM files of CAD model ▪ Compile bid with special software ▪ Give owner a disk copy of proposal	▪ Download CAD files from network ▪ Obtain bids from subs electronically ▪ Transmit file via network to owner

Table 9: Characteristics and examples of technology levels