Informatization Index for the Construction Industry

Youngsoo Jung, A.M.ASCE[1]; Sangyoon Chin, M.ASCE[2]; and Kyungrai Kim, A.M.ASCE[3]

Abstract: It is normally recognized that information systems (IS) in the construction industry have not been sufficiently used in the era of information. However, so far no serious comprehensive effort has been made to measure the degree of informatization at the industry level. In order to address this problem, in this paper we propose an informatization assessment methodology for the construction industry. An informatization index for the construction industry (IICI) is developed based on specifics of the construction industry. A survey using IICI was conducted among general contractors in Korea, and the results are analyzed in terms of the measure of assessment, IS phases, construction business functions, and size of the firm. It is found that the proposed methodology can provide meaningful indicators that can be used in quantitative comparative assessment from many different perspectives. Details and implications of the case study are briefly presented.

DOI: 10.1061/(ASCE)0887-3801(2004)18:3(267)

CE Database subject headings: Information systems; Information technology (IT); Assessment; Indexing; Construction industry; Strategic planning.

Introduction

Recent advances in information technology (IT) have greatly improved productivity in all sectors of industry. The general role of information systems (IS) has also changed in organizations. The traditional role of IS had been to support business functions by replacing labor-intensive actions. However, as the use of information systems has become widespread and deeply integrated into business processes, the role of IS has expanded to include support for or even shaping of corporate strategy (Bakos and Treacy 1986; Henderson and Venkatraman 1993). At present, information is a key corporate resource and is widely recognized as facilitating not only effective project management, but also automation in engineering and construction.

The intensity or degree of computerization can vary widely across nations, industries, and organizations. Assessment of IT utilization must be objective as well as comparative. Therefore, comprehensively measuring IS status (informatization), can provide meaningful insights and guidelines. However, the construction industry has been relatively slow to deploy information technology (Nam and Tatum 1992; Tucker et al. 1994; Betts 1995; Mak 2001), and there has been lack of a systematic effort to evaluate the overall IS status within the construction industry. If the industry is to have purposeful vision and a plan for widespread adoption of IS, it is essential that the status of IS is measured and understood systematically.

The purpose of this study is to develop a methodology for assessing informatization in the construction industry. The proposed methodology involves quantifying issues relevant to IS usage within the construction industry with an eye toward evaluating the current situation, identifying areas for improvement, and suggesting plans for further development. A survey was conducted to investigate the state of informatization of Korean general contractors, as well as to evaluate the viability of the proposed methodology. Findings and practical implications are outlined.

Informatization

Kluver (2000) defined informatization as ''a process whereby information and communication technologies transform economic and social relationships so that cultural and economic barriers are minimized.'' Hannah et al. (1995) defined the level of informatization as the percentage of workflow supported by IT, and classifies it into (1) substitution of technologies, (2) enhancement of processes, and (3) transformation of organization and strategy. Kluver (2000) interpreted the concept of informatization more or less from a socioeconomic perspective, while Hannah et al. (1995) focused on organizational concerns. Notwithstanding this slight divergence in viewpoints, the terms they use are common for defining IT and IS use.

To assess informatization in construction organizations, an informatization index is defined in this study as ''a quantitative and comparative indicator that represents the level of IS in terms of its infrastructure, effectiveness, and interaction with the organizational environment.'' Characteristics, methods of assessment, and relevant considerations in assessing informatization are briefly investigated.

Information Systems Assessment

Assessing the organizational value of an IS is a complex difficult task. As previously discussed, information systems are now

[1]Associate Professor, College of Architecture, CAUD, Myongji Univ., Yongin 449-728, South Korea.

[2]Associate Professor, Dept. of Architecture, Landscape Architecture, and Civil Engineering, Sungkyunkwan Univ., Suwon 400-746, South Korea. E-mail: schin@skku.ac.kr

[3]Assistant Professor, Dept. of Architecture, Ajou Univ., Suwon 442-749, South Korea.

Note. Discussion open until December 1, 2004. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on February 12, 2003; approved on December 10, 2003. This paper is part of the ***Journal of Computing in Civil Engineering***, Vol. 18, No. 3, July 1, 2004. ©ASCE, ISSN 0887-3801/2004/3-267–276/$18.00.

deeply integrated into business processes. Moreover, intangible benefits of IS, such as increased effectiveness, improved accuracy, and competitive advantages gained are hard to quantify.

Ginzberg and Zmud (1986) noted that traditional information systems assessment (ISA) has mainly concentrated on the technical, operational, and economic evaluation of IS. Among these evaluations, cost/benefit analysis is the one most commonly used, and is most accurate in terms of being measured. However, this popular approach addresses economic issues alone, and rarely incorporates technical and operational considerations (Ginzberg and Zmud 1986). Therefore, Hirschheim and Smithson (1986) argued that these analytical (objective/rational) techniques should be combined with an interpretive (subjective/political) perspective, because technical evaluation without social dimensions can distort the decision-making process.

Other considerations in relation to ISA have also been examined. Davis and Srinivasan (1986) stressed the importance of user diversity (direct, autonomous, and indirect) in ISA. Etzerodt and Madsen (1986) pointed out the importance of the educational perspective, in that people in an organization can learn about their work and information systems by participating in ISA. Davenport and Short (1990) pointed out that, generally, although IT managers tend to think that building up hardware and systems would produce a synergy effect through information sharing among users, the best IT equipment does not guarantee efficient information management.

Within these complex considerations, ISA itself has difficulties of ''subjectivity,'' mainly because intangible benefits are hard to quantify. Difficulties also exist because of the ''variety'' of issues, as discussed in the ISA literature (Hawgood and Land 1986). Thus, ISA needs to focus less on subjectivity and more on business and social-environmental issues.

Informatization Assessment

Even though the concepts of ISA and informatization assessment (IA) are very similar, IA in this study is characterized by its comparative nature. In other words, IA concerns the assessment of an organization, an industry, or a nation in relation to its competitors in almanac form, whereas ISA focuses more on internal evaluation within an organization.

Literature that examines IA from a national perspective includes work by Machlup (1962), Porat (1977), Johnscher (1983), International Data Corporation IDC (1996), and the National Computerization Agency (1996). Machlup (1962) defined the ''knowledge industry'' and estimated the ''knowledge production'' of a nation in terms of the percentage of gross national product (GNP). Porat (1977) and Johnscher (1983) also used macroeconomic measures for determining the level of informatization. IDC defined IA using more detailed measures. The information imperative index (III) developed by IDC (1996) consists of three categories (social infrastructure, information infrastructure, and computer infrastructure) and 20 subordinate measures (for example, cable/satellite TV coverage, having PCs installed, owning a fax, Internet hosts per 1,000, software/hardware expenditures, tertiary school enrollment, networked PCs, owning cellular phones, newspaper readership, Internet service providers, and so forth). This index ranked 55 countries that account for 97% of the world's gross domestic product (GDP) and over 99% of all IT spending. The III has recently been revised as an annual information society index (ISI) by adding a category for ''Internet infrastructure'' that consists of four different subordinate measures (Information Society 2002). Several reports in Korea (Korea Information Society 1989; National Computerization Agency 1996) have also applied these types of informatization measures. Macroeconomic measures such as telephone lines per 100, Internet hosts per 1,000, number of IT researchers per 100, and so forth are included in these reports. It is significant that in the report by the National Computerization Agency (1996), these measures are categorized into three groups: information infrastructure, information usage, and investment and manpower.

There have been several IA efforts at the industry level as well. The Information Week 500 (2002) report annually surveys and analyzes the informatization status of U.S.-based enterprises with more than $1 billion in annual revenue. It surveys business technology practices and investments in areas such as customer collaboration, enterprise software, e-business applications, outsourcing, company policies, and IT-relevant expenses. The survey covers 22 industries, including construction and engineering. A similar survey conducted by the Japan User Association of Information System (JUAS) annually surveys the state of enterprise informatization in Japan. The survey includes small-and medium-sized companies too. The assessment measures used by JUAS include management problems, relationships between top management and IT managers, level of IS achieved, obstacles, future objectives, top management awareness, IT investment and costs, training and education, and evaluation of IT managers. IT Research & Consulting (2001) in Korea evaluates enterprise informatization using its own evaluation framework that includes six areas: goals, equipment, environment, support, application, and utilization of informatization.

IA variables used in previous research differ depending on the research objectives. It is also clear that, even within a single study, the variables evolve as informatization environments change. To summarize, the variables used for IA include macroeconomic significance, social infrastructure, business environment, IT diffusion, IS utilization, Internet applications, organizational policies, IS expenses, process improvement, and user involvement.

Informatization in Construction

Although many of the ISA and IA studies introduced above use various different measures to assess informatization, no systematic attempt has been made to identify informatization characteristics specific to the construction industry. Most existing assessments are either nationwide (Machlup 1962; Porat 1977; Johnscher 1983; International Data Corporation 1996; Organization for Economic Cooperation and Development 2002) or cross-industry (ITR 2001; Information Week 500 2002; JUAS 2002).

Few studies in the area of construction have addressed this issue. For example, one study investigated IT solutions in the Architecture/Engineering/Construction (A/E/C) industry using interviews and discussions with practitioners in seven countries that were based on various issues such as computer-aided design (CAD), electronic document management (EDM), legal, contractual issues, etc. (AEC3 1999). However, this study was limited to identifying the status and concept of informatization in the industry with no objective results presented.

A couple of relevant studies have analyzed the IS issues in a quantitative manner but within specific areas. With focus on the impact of enterprise resource planning (ERP) systems of capital projects, O'Connor and Dodd (2000) identified requirements and needs for improvement in three areas of ERP, functional, technical, and usability issues. Thomas et al. (2001) investigated the

impact of IT on project performance. The degree of IT use in that study concentrated on the computer applications used.

Assessment Issues in Construction

ISA issues in the construction industry are discussed in several studies, all of which stress the uniqueness of the industry. Betts (1995) developed a five-level framework for strategic IS in the construction industry. The five levels include the national construction industry, professional institutions, construction enterprises, construction projects, and construction products. Peña-Mora et al. (1999) pointed out another aspect, a temporary project organization composed of multiple firms. These variables give a meaningful point of departure for organizing IS categories in the construction industry. In their development of an IS planning methodology for construction firms, Jung and Gibson (1999) defined computer-integrated construction (CIC) as ''the integration of corporate strategy, management, computer systems, and information technology throughout the project's entire life cycle and across different business functions.''

It can be seen that in considering IS issues in the construction industry, there are some specific factors which are highly significant, including the project's life cycle, construction business functions, and fragmented organizations. Construction business functions are a significant factor, since a construction organization consists of many different divisions, and the divisions share a lot of information in common in their various processes. Even state-of-the-art ERP has difficulties in meeting the requirements of construction business functions (O'Connor and Dodd 2000). Without efficient information exchange among divisions, it is more difficult to achieve objectives of the construction business. Similarly, it is also critical to have a strategy for efficient information exchange among stakeholders in a construction project. Business effectiveness through integration, the drive for standardization in business processes, and promptness of communications and decision-making also need to be carefully considered.

These factors will be considered in this study in order to identify assessment variables for use in a framework designed to facilitate more a detailed effective IA in the construction industry.

Assessment Variables in Construction

Based on the aforementioned comprehensive reviews in the literature, a lengthy list of eligible variables was developed first. The writers then conducted a set of workshops in order to identify and organize IA variables for the construction industry. Experience in real world situations was also included since one of the writers had worked for several years as an IS manager in a large construction company. The list of variables and measures has been verified by industry experts through a preliminary survey.

Three major variables identified were assessment measures, IS phases, and construction business functions. These variables actively involve business and social-environmental issues within construction firms, and are defined in a measurable manner in order to meet the requirement of being less subjectivite discussed earlier.

Assessment Measures

In order to encompass not only the ISA and IA considerations but also characteristics of the construction industry itself, 14 measures were identified in the workshops. Even though the three categories of information infrastructure, information usage, and investment and manpower used by the National Computerization Agency (1996) are somewhat different from those used in this study in terms of their content and perspective, the basic concept was modified and adapted to classify the 14 measures used in this study. Finally, the 14 measures are grouped into three assessment categories: ''infrastructure,'' ''utilization,'' and ''support,'' as shown in columns 1 and 2 of Table 1.

The first category, IS infrastructure, is defined in this study as basic components of the IS environment that are needed to provide convenience for information users and to increase productivity. Computer hardware, computer network, standardization, and database are the assessment measures included in this group. Second, utilization denotes the actual use of the IS infrastructure in an adequate manner. This category embraces the computerized processes inside or outside an organization and also considers infrastructure adaptability for user satisfaction. System integration, intraorganizational use, interorganizational use, and user satisfaction are the measures used in this category. Finally, the category support indicates material and nonmaterial support in terms of providing infrastructure and increased effective use of the infrastructure. Strategic fit, management policy, planning, investment, education, and IS organization are included in this group.

Information Systems Phases

Three IS development phases, ''awareness,'' ''development,'' and ''exploitation,'' are used as one variable in IA for the construction industry. It is assumed that an organization would start with awareness of IS needs and then develop the systems. In the final stage, the systems developed are exploited to maximum advantage. The most suitable phase for each measure is selected based on the content and description of the questions assigned to each measure in the questionnaire. Even though the questionnaires are not included in this paper because they are lengthy, descriptive explanations are given for clearer understanding. Note that each phase is not necessarily proportional to each of the others. For example, an organization with technically satisfactory IS may not take full advantage of in the exploitation phase.

The rationale behind this variable is that informatization of the construction industry is not yet very advanced. Therefore, the level of informatization in each phase can provide an explicit guideline for IS decision making for the industry.

Construction Business Functions

Defining construction business functions varies from organization to organization. The major variation here is in the level hierarchy at which business functions are grouped in different organizations, or even within an organization.

In order to ensure universal application to any construction-related firm, 14 construction business functions defined by Jung and Gibson (1999) were used in this study: planning, sales, design, estimating, scheduling, materials management, contracting, cost control, quality management, safety management, human resource management, finance/accounting, general administration, and R&D. This classification of 14 business functions is detailed enough to analyze the business characteristics of construction firms, and brief enough to conduct surveys at the company level.

Informatization Assessment Framework

Three variables of assessment measures, IS phases, and construction business functions are identified for IA in construction. These variables are independent of each other in nature, and each of them may be viewed in terms of other variables as shown in Fig. 1.

Table 1. Measures for Informatization Assessment

Category[a]	Measure	Item	IS phase	Business functions[b]	Scale
Infrastructure	Computer hardware	Number of personal computers per capita	Development		Percentage
		Adequacy of computer distribution	Exploitation		Multiple choices
	Computer network	Number of job sites connected (%)	Development		Percentage
		Network speed (head office)	Development		1–5
		Network speed (job site)	Development		1–5
		Level of network security	Exploitation		1–5
		Adequacy of current network systems	Exploitation		1–5
	Standardization	Level of standardization for office automation	Exploitation		1–5
		Level of using standard classification codes	Exploitation	Classified	1–5
	Database	Preservation of historical database	Exploitation		1–5
Utilization	System integration	Awareness of needs for systems integration	Awareness		1–5
		Use of integrated systems	Development	Classified	Multiple choices
	Intraorganizational use	Awareness of needs for intraorganizational IS	Awareness	Classified	1–5
		Level of intraorganizational IS use	Exploitation	Classified	1–5
	Interorganizational use	Awareness of needs for interorganizational IS	Awareness	Classified	1–5
		Level of interorganizational IS use	Exploitation	Classified	1–5
	User satisfaction	Degree of business processes computerized	Exploitation		1–5
		Degree of satisfaction and accuracy	Exploitation		1–5
Support	Strategic fit	Awareness of needs for strategic fit	Awareness		1–5
		Degree of strategic IS planning	Development		1–5
		Degree of strategic IS development	Development		1–5
		Degree of strategic IS utilization	Exploitation		1–5
	Management policy	Emphasis on IS utilization by CEO	Awareness		1–5
		Incentives for IS utilization	Exploitation		1–5
	Planning	Awareness of needs for long-term IS planning	Awareness		1–5
		Fulfillment of long-term IS planning	Development		1–5
	Investment	Annual IT investment (% of annual sales)	Development		Percentage
		Adequacy of annual IT investment	Exploitation		1–5
	Education	Percentage of attendance at IT training courses	Development		Percentage
		Adequacy of IT training hours		Exploitation	1–5
		Effectiveness of IT training	Exploitation		1–5
	IS organization	Number of full-time IS staff	Development		Percentage
		Adequacy of number of IS staff members	Exploitation		Multiple choices

[a]The basic concept of three categories defined by NCA (1996) has been modified and adapted.

[b]Questions for each item were reclassified by business functions.

The two major dimensions are assessment measures and IS phases. As depicted in Fig. 1, the vertical axis represents the informatization assessment measures divided into three categories, whereas the horizontal axis indicates the three IS phases. Each measure (listed in column 2 of Table 1) in three categories (column 1 of Table 1) on the vertical axis consists of one or more items (column 3 of Table 1) that are assigned to an IS phase so that the measures can be interpreted according to IS phases. The detailed relationship between these two variables is explained in columns 1, 2, and 3 of Table 1.

A similar relationship can be found between assessment measures and construction business functions. For example, the ninth row under the title in Table 1 shows that the item, ''Level of using standard classification codes,'' as a ''standardization'' measure, may relate to the IS ''exploitation'' phase, and it is desirable to understand how the levels of standardization vary between many different construction business functions.

Columns 2, 4, and 5 of Table 1 summarize the relationship among the three variables used in this study. Table 1 was used as a base for developing survey questionnaires.

The proposed framework can be used in a more detailed manner from many different perspectives. For example, the shaded cells on the left-hand side of Fig. 2 form a combined category

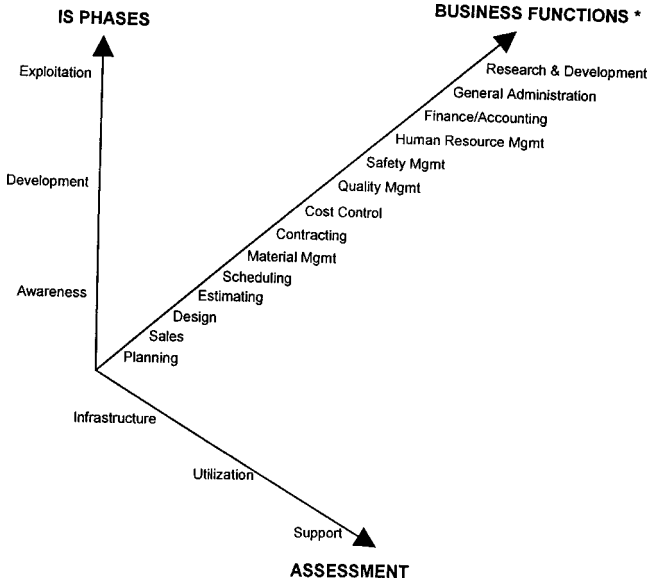

Fig. 1. Framework for informatization assessment

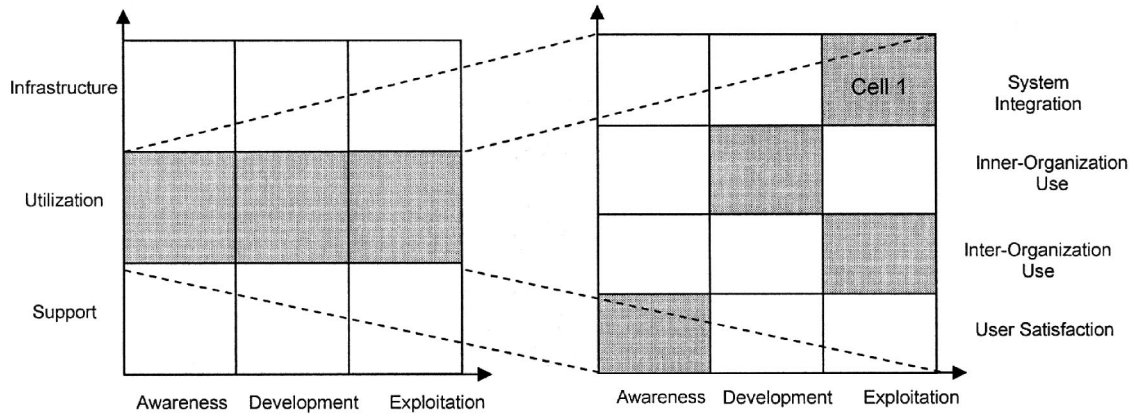

Fig. 2. Areas of measurement for informatization index (example)

made up of utilization assessment measures, presented on the vertical axis, and the IS phases, presented on the horizontal axis. The part on the right-hand side of Fig. 2 shows an example of a decomposed classification for the shaded cells. Note that the utilization category is further divided into system integration, intraorganizational use, interorganizational use, and user satisfaction evaluation in Table 1. Thus, cell 1 in Fig. 2 represents a result that measures system integration as the assessment measure and exploitation as the IS phase.

Assessment Methodology

In order to encompass many different perspectives in a single index, the IA variables should be able to be measured by a quantitative comparative method. An informatization index for the construction industry (IICI) has been developed in this study using the IA framework described in Fig. 1 and Table 1.

Structure of Informatization Index

The proposed IICI consists of all 3 categories (column 1 of Table 1) and 14 assessment measures (column 2 of Table 1) to provide a single composite index. Each measure then consists of one to four items (column 3 of Table 1) that can be quantified using a set of questionnaires. The total number of items is 33.

The average score for items in a measure is used as the score for each measure. The weighted score for each measure is then obtained by multiplying the weightings, and the sum of weighted scores for all measures within a category yields the score for that category. Finally, an overall IICI score is totaled by adding weighted scores for three categories. Evaluation and weighting of assessment measures are discussed in the following.

Weighting of Informatization Index

Synthesizing many different measures and items in a single index also requires a normalizing mechanism, because simply calculating the average score for all measures cannot be accurate, since the impact of each measure on informatization may vary. Two principal methods are used in this study to satisfy this requirement.

First, the scores for each of the 3 categories and the scores for each of the 14 measures in the subordinate hierarchy are balanced by multiplying the weighting and then totaling them. The analytical hierarchy process (AHP) developed by Saaty (1982) is used to acquire these weightings. Weightings at the item level are not considered because of the complexity of the analyses and the questionnaires.

Second, the same scale of percentile points is employed for final evaluation. Even though three different methods—a 1–5 scale, percentage, and multiple choice—were initially used in questionnaires to quantify the 33 assessment items (column 6 of Table 1), all the final scores for each item were converted into percentile points to facilitate the totaling and comparison process.

Index Rating for Weighting

A group of construction IT experts invited to participate in the workshop derived the relative weighting among three different categories and among several different measures in a category through the AHP pair-wise comparisons developed by Saaty (1982). Eleven experts with knowledge of the construction industry and of information systems, and general contractors participated. Five of them were general contractors, four were from research institutes, and two were from owner organizations. Definitions of the categories and measures of IICI were explained to the 11 experts before they filled out the questionnaires. They were asked to consider the current IT environment and resources that general contractors face in Korea in performing AHP pair-wise comparisons.

To assure the reliability of the responses, only answers with less than a 10% consistency ratio (Saaty 1982) were used. The results show that the weightings in the three categories (infrastructure, utilization, and support) were 32.34, 30.44, and 37.22%, respectively. The results for measures and items are listed in Table 3. These weightings form an index that can determine the combined level of informatization:

$$\text{IICI} = I \times 0.3234 + U \times 0.3044 + S \times 0.3722 \quad (1)$$

where I = percentile score for that IS infrastructure; U = percentile score for IS utilization; S = percentile score for IS support. *I*, *U*, and *S* decompose into 14 measures with normalized weightings.

The results of AHP analysis show only slight differences in the degree of importance among the three categories of IICI. It is notable that the results showed IS support as being the most important category (37.22). IS planning ranked relatively high (20.45) among the six items in the support category.

As for the infrastructure category, standardization ranks high-

Table 2. Survey Schedule

Part	Description	Method of surveying	Respondent	Number sent out	Number of responses	Usable responses	Date
I	Index rating for weightings	Questionnaire and workshop	Experts	11	11	11	October 2001
II	Preliminary survey	Questionnaire	IS managers	12	5	5	August 2001
III	Main survey	Questionnaire	IS managers	300	49	37	September/October 2001
IV	Interview	Questionnaire and interview	IS managers	17	17	17	October 2001
	Total				82	70	

est (35.69), and database is second (30.11) among the four measures. This means that standardization and database need more effort and resources due to their significant impact on informatization.

Three measures are ranked in the utilization category in the following order: user satisfaction (31.84), system integration (27.98), and intraorganizational use (26.12). This is because system integration and organizational use measures reflect recent informatization action, such as process integration between different business functions and network integration between headquarters and construction sites, and user satisfaction is one of the critical factors for successful system integration and utilization. However, the lowest weighting, for interorganization use (14.06), indicates that information exchange between different organizations still had a low profile at the time of the survey in 2001.

The relative weightings identified here may vary as the construction environment changes. Nevertheless, the proposed IICI framework and methodology can be used to continuously evaluate informatization in the construction industry.

Survey and Results

A survey that used the IICI methodology was conducted in 2001 to evaluate the status of informatization of general contractors in Korea and to validate the methodology. The survey took about 3 months and was made up of four parts, and three different questionnaires, were used; they are listed in Table 2.

Outline of Surveys

A questionnaire was sent to 12 large construction companies as a preliminary survey. Five companies responded with comments and suggestions. Valuable ideas for improving IS utilization in the construction industry were gathered, and the overall structure and descriptions in the draft questionnaire proved to be valid. Some sentences, words, and formats were changed for easier comprehension of the main survey.

In Korea, 7,978 general contractors were registered in 2000. Most of them are not aware of the necessity of IS. It is judged that only the top 300 general contractors use IS and have a division to support it. Therefore the top 300 Korean general contractors were sampled for this survey by judgment sampling. The survey sample was selected primarily on the basis of the company's annual sales in the year 2000. This group can be subdivided into three groups: large companies (1st–80th), midsize firms (81st–200th), and small firms (below 201st). Only 49 companies replied, a response rate of about 16%. Of these responses, 37 (18 from large firms, 12 from midsize firms, and 7 from small firms) could be used for analysis. In spite of the fact that the researchers had expended a great deal of effort to keep the questionnaire concise and straightforward, it was found during the telephoning process that the 4-page questionnaire with 37 questions was still difficult for general contractors to answer. Many midsize or small companies had no staff member responsible for IS management, and even large companies had some difficulty in collecting relevant data after circulating the questionnaire. This suggests that, in the construction industry, IS management is itself an area which needs to be improved as well.

IICI scores for each company and average scores by measures were analyzed from many different perspectives. The data were interpreted in terms of assessment measures, IS development phases, construction business functions, and firm size.

Additional interviews using a more detailed questionnaire were carried out as follow-up to the main survey. This questionnaire followed up in detail IS items and spending on these items, descriptive IS policies and objectives, frequency and type of IS use, and so on. Seventeen large companies that replied with usable responses willingly scheduled a visit. Valuable information was gathered, and implications of the main survey results were further investigated through interviews.

Results by Assessment Measures

The IICI score for each company was determined using the methodology proposed above. The average IICI score for 37 Korean general contractors was found to be 67.15, 100 indicates the ideal level for companies to achieve the most effective satisfactory infrastructure, utilization, and support of IS in their organizations. In other words, a score of 100 can be obtained if every single question is given a perfect score. The highest score was 90.56, and the lowest was 50.88, with standard deviation of 10.65.

Average scores, standard deviations, and weightings for categories and measures are listed in Table 3. Percentile scores for the three categories of infrastructure, utilization, and support are 67.93, 68.37, and 65.47, respectively.

It is of note that the support category obtained the lowest score (65.47) in the survey while registering the highest weighting (37.22) in index rating. This category also showed the biggest standard deviation (14.32) and the strongest correlation (0.91) with final IICI scores. The result implies that Korean general contractors are generally aware of the importance of IS, even when IS investment is not adequate, especially after the International Monetary Fund (IMF) bailout in Korea. Different weightings and scores would have been obtained if the same survey had been conducted before that financial crisis at a time when large construction companies in Korea had invested satisfactory amounts of money.

Zero-order correlation analysis shows that all measures except interorganizational use and IS organization are significant ($p < 0.01$). Among the measures in the support category, strategic fit and planning show a relatively strong correlation (0.86 and 0.81, respectively) with the IICI scores, and the planning measure indicates a relatively wide standard deviation (23.22). In addition,

Table 3. Survey Results by Measure

Category	Measure	Score		Weight	IICI value[b]	Correlation analysis[c]		
		Average	Std. dev.			Zero-order correlations[e]	Partial correlation[e]	Controlled measure[f]
Infrastructure	Computer hardware	79.42	16.02	4.99	3.96	0.489[d]	0.227(0.184)	Planning (0.458[d])
	Computer network	58.81	18.44	6.07	3.57	0.703[d]	0.383(0.021)	Planning (0.662[d])
	Standardization	72.16	13.97	11.54	8.33	0.444[d]	0.082(0.634)	Strategic fit (0.475[d])
	Database	62.70	18.69	9.74	6.11	6.641[d]	0.421(0.10)	Computer network (0.558[d])
	Subtotal	(67.93)[a]	11.06	32.34	21.97			
Utilization	Systems integration	75.14	22.13	7.61	5.72	0.521[d]	0.201(0.236)	Computer network (0.573[d])
	Intraorganizational use	69.62	12.55	9.36	6.52	0.597[d]	0.274(0.106)	Computer network (0.635[d])
	Interorganizational use	54.81	17.61	4.49	2.46	0.109(0.520)	–	–
	User satisfaction	68.11	15.04	8.98	6.12	0.747[d]	0.528[d]	Education (0.655[d])
	Subtotal	(68.37)[a]	10.45	30.44	20.81			
Support	Strategic fit	72.84	14.36	5.80	4.22	0.856[d]	0.685[d]	Planning (0.707[d])
	Management policy	62.70	18.11	6.22	3.90	0.718[d]	0.474[d]	Education (0.655[d])
	Planning	72.97	23.22	7.61	5.55	0.806[d]	0.548[d]	Strategic fit (0.707[d])
	Investment	61.89	19.71	7.55	4.67	0.714[d]	0.520[d]	Education (0.588[d])
	Education	65.41	16.39	4.68	3.06	0.714[d]	0.462[d]	User satisfaction (0.656[d])
	IS organization	55.14	17.18	5.36	2.96	0.232(0.167)	–	
	Subtotal	(65.47)[a]	14.32	37.22	24.37			
Total		67.15	10.65	100	67.15	1.00		

[a]The scores in the parentheses in column 3 are percentile scores of the subtotals, namely, (column 6)/(column 5)×100.

[b]IICI value for each measure (column 6)=(column 3)×(column 5)/100.

[c]A two-tailed significance test of the correlations was used.

[d]$p<0.01$.

[e]Numbers in parentheses are p values.

[f]Numbers in parentheses are correlation coefficients with corresponding measures.

user satisfaction in the utilization category shows a strong correlation (0.75).

Partial correlation analysis is also conducted to eliminate the impact of a measure that has the highest correlation coefficient. The result showed that six measures, strategic fit, planning, user satisfaction, investment, management policy, and education, have a strong relationship to the index.

This implies that strategic fit, planning, and user satisfaction are the most important factors that affect successful IS implementation in the construction industry. This is supported by Jung and Gibson's research (1999), which concluded that managerial issues (corporate strategy and management) are more determining variables throughout the planning process in helping to make IS in a construction firm more viable and efficient.

Results by Information Systems Phases

As discussed earlier, the measures and items listed in Table 1 can be subdivided into three groups in terms of IS phases. The scores based on IS phases can be obtained by averaging only those items in the same phase. For example, scores for the six items marked awareness, that is, the 11th, 13th, 15th, 19th, 23rd, and 25th rows in column 4 of Table 1, were averaged to score the awareness phase. The result shows that the average percentile scores of 37 respondents as 79.73 for awareness, 64.48 for development, and 62.89 for exploitation. It can be concluded that Korean general contractors' level of IS awareness is relatively higher than the level of IS development and exploitation in their organizations.

Another interesting point is that, as shown in Table 4, the companies within the upper 25th percentile in terms of IICI scores show very high scores in awareness (88.06) and the lowest standard deviation (4.71).

These results have two opposite implications; one is very encouraging, since more effort and investment may occur in the near future, and the other is very discouraging, in that, although they recognize the need for information systems, firms have not done enough in the way of construction and utilization. This seems to be more obvious in firms with lower IICI scores, since gaps in averages among awareness, development, and exploitation phases are bigger. However, it would be worthwhile to carry out surveys for several successive years in the future to analyze trends in the development phase.

Table 4. Survey Results by Information Systems Phase

Phase	All respondents		IICI upper 25%		IICI middle 50%		IICI lower 25%	
	Average	Std. dev.	Average	Std. dev.	Average	Std. dev.	Average	Std. dev.
Awareness	79.73	11.10	88.06	4.71	79.18	10.94	72.34	10.27
Development	64.48	16.75	83.95	4.95	64.89	9.85	44.33	7.95
Exploitation	62.89	11.64	78.41	6.79	60.64	5.08	51.19	4.98

Table 5. Survey Results by Business Function

Business functions[a]	Intraorganization IS[b]			Interorganization IS[b]		
	Awareness	Exploitation	Discrepancy	Awareness	Exploitation	Discrepancy
Planning	72.43	54.05	18.38	59.46	38.38	21.08
Sales	78.92	63.78	15.14	70.27	44.32	25.95
Design	69.73	46.11	23.62	69.73	40.54	29.19
Estimating	85.41	59.46	25.95	73.51	46.49	27.03
Scheduling	84.32	54.59	29.73	70.81	41.08	29.73
Materials management	82.16	67.03	15.14	74.05	45.95	28.11
Contracting	83.78	63.24	20.54	78.92	54.05	24.86
Cost control	85.41	68.11	17.30	68.11	44.86	23.24
Quality management	78.38	54.59	23.78	70.81	43.24	27.57
Safety management	71.35	52.97	18.38	65.41	40.54	24.86
Human resources management	82.16	72.97	9.19	57.84	35.68	22.16
Finance/accounting	88.65	82.70	5.95	61.08	42.16	18.92
General administration	72.97	61.62	11.35	57.84	38.92	18.92
R&D	65.41	45.95	19.46	60.54	40.00	20.54
Average	78.65	60.51	18.13	67.03	42.59	24.44

[a]Business functions defined by Jung and Gibson (1999).

[b]Paired comparison *t*-tests were used.

Results by Business Functions

Selected measurement items are surveyed within the dimension of construction business functions, described in column 5 of Table 1. For example, one survey question (row 14 of Table 1) asked about the ''level of intraorganizational IS use'' for each different construction business function.

Table 5 summarizes the results for intra- and interorganizational use of IS. The findings indicate that ''financing and accounting'' utilizes intraorganizational IS most in terms of awareness and exploitation, while scheduling ranks highest in terms of the discrepancy between need and actual use. Currently, the most vital use of interorganizational IS in the Korean construction industry is found to be in ''contracting'' (54.05).

Selected results for other measures show that standard classification codes are most frequently used for ''estimating'' and ''cost control.'' The three business functions, cost control, materials management, and finance/accounting, registered high scores from the viewpoint of database and system integration measures.

Results by Firm Size

As shown in Table 6, average IICI scores for large, midsize, and small firms were 70.82, 64.61, and 59.66, respectively. The standard deviations for these three groups were 11.41, 10.13, and 6.76, respectively. Even though the large firms scored higher average indices, standard deviation was also wide. The measures

Table 6. Survey Results by Firm Size

Category	Measure	Average score			
		All firms	Large firms	Midsize firms	Small firms
Infrastructure	Computer hardware	79.42	86.23	67.01	75.71
	Computer network	58.81	68.80	52.66	37.71
	Standardization	72.16	71.76	72.00	75.71
	Database	62.70	67.06	64.00	45.71
	Subtotal	(67.93)	(72.02)	(65.19)	(59.55)
Utilization	Systems integration	75.14	86.47	80.00	41.43
	Intraorganizational use	69.62	73.50	64.57	64.90
	Interorganizational use	54.81	48.36	58.86	58.98
	User satisfaction	68.11	72.94	67.00	58.57
	Subtotal	(68.37)	(72.87)	(68.30)	(56.29)
Support	Strategic fit	72.84	75.59	70.00	66.43
	Management policy	62.70	66.47	59.00	61.43
	Planning	72.97	80.20	69.00	55.24
	Investment	61.89	66.47	51.00	60.00
	Education	65.41	68.63	58.67	64.76
	IS organization	55.14	46.47	59.00	71.43
	Subtotal	(65.47)	(68.09)	(61.09)	(62.51)
Total	IICI total	67.15	70.82	64.61	59.66
	Standard deviation	10.65	11.41	10.13	6.76

that showed a remarkable discrepancy in average score between large and small firms were ''computer network'' (68.80 versus 37.71), ''systems integration'' (86.47 versus 41.43), ''planning'' (80.20 versus 55.24), and ''IS organization'' (46.47 versus 71.43).

In terms of IICI scores, it was found that large companies obtained higher scores on average. The coefficient of correlation between the rank by volume of annual sales and IICI score was found to be 0.36 ($p=0.029$) at the 95% confidence level. However, the partial correlation analysis with control of the systems integration measure results in a coefficient of 0.0879 ($p=0.610$), therefore the size of a company is not a determining factor in the IICI score.

It is interesting that the average score for small firms for IS organization is higher than that for large firms. However, this is because the ratio of the number of IS staff members to total employees in small companies is much higher, and only a limited number of staff members handles IS administration. The results reveal that large firms have 30 employees on average, while mid- and small-size firms have, respectively, 9 and 4 employees on average in their IS organizations.

Conclusions

Researchers and practitioners in the construction industry have repeatedly asserted that utilization of information systems has not flourished for them as it has in other sectors of industry. Nevertheless, there has been no systematic effort at the industry level to evaluate the current state of informatization and to plan for the future.

In order to address this issue, this research has proposed a methodology for assessing informatization in the construction industry. The proposed methodology reflects characteristics of the industry, making it possible not only to determine the current level of informatization, but also to forecast future levels.

A single index, the IICI, was developed to incorporate comprehensive elements for informatization assessment. Three major variables (assessment measures, IS phases, and construction business functions) were decomposed into 31 items. A survey of Korean general contractors verifies that the framework and methodology of the proposed IICI is comprehensive and specific enough to be universally applicable in the construction industry. To incorporate many different measures, the scores were simplified for each measure. However, the data collected through the survey consisted of a huge amount of perceptual and archival data. Partial use of these data in a given time period or a time series would also provide valuable implications.

Although case specific to this study, the fact that strategic fit, planning, and user satisfaction are factors with the greatest impact on IICI scores implies the importance of strategic and managerial issues in IS development. The score of IS awareness is some what higher than that for development or exploitation, which means that firms with higher IICI scores would make more effort and investment in the near future, however others with lower IICI scores have not taken enough action for construction and utilization although they recognize the need for information systems. Another interesting fact is that financing and accounting is the business function that most widely utilizes IS, and scheduling is the business function that could be improved most effectively through informatization in the industry. These types of information help to identify starting points for further detailed plans and analysis. This way, the proposed methodology can be used in many different ways, for example, as a guide for the government in directing IS policy, or to provide fundamental data to help an organization analyze its IS performance.

This paper is limited to the perspective of general contractors. The methodology may not represent the overall characteristics of other project stakeholders such as owners, architects and engineers, subcontractors, and suppliers. In future research, continuous development and refinement of the assessment method presented in this paper may help to monitor the annual status informatization and trends in the construction industry. Furthermore, investigation of the use of the average only method and analysis of the differences in results between the two methods would provide additional meaningful insight into informatization in the construction industry.

Acknowledgments

The writers would like to acknowledge the financial support provided by Grant No. R01-2003-000-10079-0 from the Basic Research Program of the Korea Science and Engineering Foundation. Special thanks to those who answered the huge amount of survey questions and agreed to interviews, despite heavy daily workloads. Graduate students Sukjae Lee, Junghan Chin, Jongdae Lee, Sehan Chang, Sanghyung Lee, and Jungha Park are also acknowledged for their painstaking assistance.

References

AEC3 Ltd. (1999). ''Applying IT strategies in the AEC/FM industsry.'' AEC3 Ltd. ⟨http://www.aec3.com⟩ (Nov. 24, 2000).

Bakos, J. Y., and Treacy, M. E. (1986). ''Information technology and corporate strategy: A research perspective.'' *MIS Q.*, 10(2), 107–119.

Betts, M. (1995). ''Technology planning frameworks to guide national IT policy in construction.'' *Autom. Constr.*, 3(4), 251–266.

Davenport, T. M., and Short, J. E. (1990). ''The new industrial engineering: Information technology and business process redesign.'' *Sloan Manage. Rev.*, 31(4), 11–27.

Davis, J. G., and Srinivasan, A. (1986). ''Incorporating user diversity into information systems assessment.'' *Proc., IFIP WG 8.2 Working Conf. on Information Systems Assessment*, 83–100.

Etzerodt, P., and Madsen, K. H. (1986). ''Information systems assessment as a learning process.'' *Proc., IFIP WG 8.2 Working Conf. on Information Systems Assessment*, 333–347.

Ginzberg, M. J., and Zmud, R. W. (1986). ''Evolving criteria for information systems assessment.'' *Proc., IFIP WG 8.2 Working Conf. on Information Systems Assessment*, 41–55.

Hannah, N., Guy, K., and Arnold, E. (1995). ''The diffusion of information technology: Experience of industrial countries and lessons for developing countries.'' *World Bank Discussion Paper No. 281*, Washington, D.C.

Hawgood, J., and Land, F. (1986). ''A multivalent approach to information system assessment.'' *Proc., IFIP WG 8.2 Working Conf. on Information Systems Assessment*, 103–124.

Henderson, J. C., and Venkatraman, N. (1993). ''Strategic alignment: Leveraging information technology for transforming organizations.'' *IBM Syst. J.*, 32(1), 4–16.

Hirschheim, R., and Smithson, S. (1986). ''A critical analysis of information systems evaluation.'' *Proc., IFIP WG 8.2 Working Conf. on Information Systems Assessment*, 17–37.

''Information Week 500.'' (2002). *Information Week*, ⟨http://www.informationweek.com/iw500⟩ (Jan. 6, 2003).

International Data Corporation (IDC). (1996). The IDC/World Times information imperative index, ⟨http://www.worldpaper.com/InfoImp/iiione.html⟩ (Dec. 20, 2000).

IT Research & Consulting (ITR). (2001). ''Evaluation indices of industrial information, Korea.''

Japan User Assoc. of Information Systems (JUAS). (2002). ''Projects of JUAS.'' JUAS, Tokyo, ⟨http://www.juas.or.jp/project/index.html⟩ (Oct. 10, 2002).
Johnscher, C. (1983). ''Information resources and economic productivity.'' *Inf. Econ. Policy*, 1(1), 13–35.
Jung, Y., and Gibson, G. E. (1999). ''Planning for computer integrated construction.'' *J. Comput. Civ. Eng.*, 13(4), 217–225.
Kluver, R., (2000). ''Globalization, informatization, and intercultural communication.'' *Am. Commun. J.*, 3(3), ⟨http://acjournalorg⟩ (Jan. 10, 2002).
Korea Information Society Development Institute (KISDI). (1989). ''National informatization index.'' *KISDI Rep. No. 89-04*, Seoul, Korea.
Machlup, F. (1962). *The production and distribution of knowledge in the United States*, Princeton University Press, Princeton, N.J.
Mak, S. (2001). ''A model of information management for construction using information technology.'' *Autom. Constr.*, 10(2), 257–263.
Nam, C. H., and Tatum, C. B. (1992). ''Noncontractual methods of integration on construction projects.'' *J. Constr. Eng. Manage.*, 118(2), 385–398.
National Computerization Agency (NCA). (1996). ''Weightings for informatization index.'' *NCA Rep. No. VII-RER-9689*, Seoul, Korea.
O'Connor, J. T., and Dodd, S. C. (2000). ''Achieving integration on capital projects with enterprise resource planning systems.'' *Autom. Constr.*, 9(5–6), 515–524.
Organization for Economic Cooperation and Development (OECD). (2002). *Measuring the information economy 2002*, OECD, Paris.
Peña-Mora, F., Vadhavkar, S., Perkins, E., and Weber, T. (1999). ''Information technology planning framework for large-scale projects.'' *J. Comput. Civ. Eng.*, 13(4), 226–237.
Porat, M. U. (1977). ''The information economy: Definition and measurement.'' Office of Telecommunications, U.S. Dept. of Commerce, Washington, D.C.
Saaty, T. L. (1982). *Decision making for leaders*, Lifetime Learning, Belmont, Calif.
The Information Society Olympiad. (2002). *The World Paper*, Boston, Feb. 13, 2002.
Thomas, S. R., Macken, C. L., and Lee, S.-H. (2001). ''Impacts of design/information technology on building and industrial projects.'' *Research Rep.*, Construction Industry Inst., Univ. of Texas at Austin, Austin, Tex.
Tucker, R. L., O'Connor, J. T., Gatton, T. M., Gibson, G. E., Haas, C. T., and Hudson, D. N. (1994). ''The impact of computer technology on construction's future.'' *Microcomput. Civ. Eng.*, 9(1), 3–11.