Strategic Advantages of Information Technology in Construction

by

Youman Kim

B.A., Architectural Engineering (2000)

Korea University

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Signature of Author...
Department of Civil and Environmental Engineering
May 5, 2003

Certified by...
Fred Moavenzadeh
Professor of Civil and Environmental Engineering
Thesis Supervisor

Accepted by...
Oral Buyukozturk
Chairman, Departmental Committee on Graduate Studies

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ABSTRACT

Over the past decades, the dramatic progress of information technology has contributed distribution of innovative systems to most of industries in the world. Such technologies offer strategic advantages to gain competitive advantage, improving productivity and performance, developing new ways of managing and organizing.

In this thesis, I explore and evaluate the impact of information technology in construction industry. I exhibit what strategic advantages can be gained from implementing innovative technologies within an organization and industry as a whole. In addition, I examine the knowledge management strategy as a part of advantages of technology. Some challenges to adopting innovations are addressed as well as the potential solutions. The purpose of this research is to provide a strategic vision for information technology in construction during the next decade.

Thesis Supervisor: Fred Moavenzadeh
Title: Professor of Civil and Environmental Engineering

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Chapter 1. Introduction

Information technology (IT) offers new opportunities as a strategic weapon to gain competitive advantage, improving productivity and performance, developing new ways of managing and organizing. Over the past decades, the dramatic progress of information technology has contributed distribution of IT systems to most of industries in the world. New technologies have been developed for networking, information sharing, database management systems, etc. While most of the these new developments have rapidly taken place in manufacturing and retail industries, the overall construction industry has been adopting new technologies in relatively slow pace.

Since there has been uncertainty in determining the distribution of benefits from innovative IT systems among the players on a project team in construction industry, each individual player has been unwilling to bear the relatively high cost of implementing the system. The situation, however, is changing as more and more firms in the construction industry started to realize the benefits of information technologies such as improved communications between the projects' participants which can lead to improve cost efficiency, better quality and competitive advantage.

In this research, I explore some significant applications of IT in detail and evaluate their effects on each player in construction projects or construction industry as a whole. Some challenges to adopting innovations are addressed as well as the potential solutions.

1.1. Statement of Purpose

The purpose of this thesis is to explore and evaluate the impact of information technology in construction industry. I provide a framework for determining what strategic advantages can be gained from implementing innovative technologies, and how the incentives will affect each organization on the project team as well as the whole construction industry. The framework developed in this research is used to provide a strategic vision for information technology in construction during the next decade.

1.2. Thesis Organization

Chapter 1 provides general introduction to my thesis topic and purpose of this research.

Chapter 2 describes some significant applications of information technology in construction and their impact on the industry. First, I take a look at some IT implementations in the area of collaboration between design and construction. Secondly, I explore some aspects in the context of interoperability. Lastly, industry wide applications are examined.

Chapter 3 discusses the knowledge management strategy as a part of IT advantage. First, I general characteristics of knowledge management and then I examine case examples of knowledge management strategy from other sectors. Secondly, I discuss the knowledge management strategy for construction industry.

Lastly, I use system dynamics model to capture some important feedbacks from knowledge management strategy within an organization.

Chapter4 discusses some challenges for implementing information technology in construction and provides potential solutions for those challenges.

Chapter 5 offers conclusion as well as insights of future directions for construction industry with regards to information technology.

Chapter 2. Significant Applications of IT in Construction

2.1. Collaboration Between Design and Construction

Integrated design and construction teams rely heavily on rapid information exchange between each team during the construction. To improve this communication process between design and construction team, many information technologies (e.g. tablet and wearable computers, wireless internet, and web-based data exchange systems, etc.) have been developed and applied recently. Those technologies can be used to:

- Provide everyone in the project team with the most current drawings and other documents so that they can reduce the risk of errors and rework.
- Save time in the query and approval process, by allowing the design and construction team to communicate on drawings online.
- Communicate changes quickly and easily during the design and construction stages.
- Eliminate the risk of losing important files, by maintaining all current and past versions in database.
- Maintain a complete log of all communications for tracking purposes.

In this section, I like to address some communication systems in detail and evaluate their impact on the collaboration between design and construction.

2.1.1. On-site Communications

Communication problems are frequently occurring at the construction jobsite, where both paper documents and electronic equipments may be easily damaged. Recently, affordable tablet and wearable computers were introduced to overcome those problems on jobsite. The use of tablet and wearable computers provides better and efficient method of communication between the fieldworkers on-site and off-site collaborators in building design and construction.

Tablet computers are similar in size to a notebook computer and use a touch-sensitive screen for input using a pen-shaped stylus. Wearable computers consist of a processing unit and batteries and could be worn on a belt. Using a wearable computer, a field worker can easily access the needed information at the point of work with a great level of accuracy and efficiency. They also provide extreme mobility and swiftness.

Figure 2-1 Tablet computer (left) and wearable computer (right)

Experimental prototypes of tablet and wearable computer have been tested at the University of Illinois at Urbana-Champaign (Liu 1995).[1] The three communication technologies tested were paper documents, pen-based tablet computer, and wearable computer with flat panel display. The result indicated that tablet and wearable computers might significantly reduce rework, while productivity decreased slightly when tablet and wearable computers were used.

The productivity was slightly lower in the projects using tablet and wearable computers than in the project using paper documents. Productive work accounted for 86% of the total project time when paper documents were used, 80% with a tablet computer, and 79% with a wearable computer.

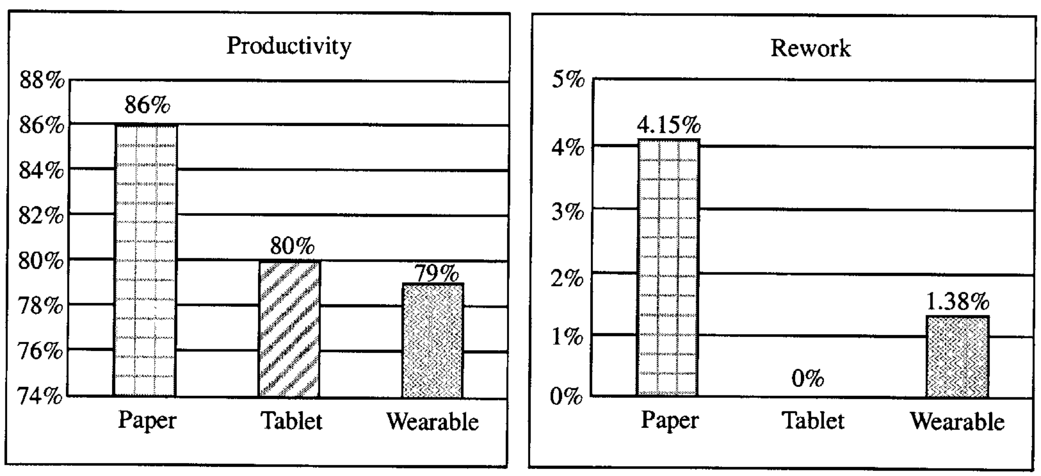

Figure 2-2. Productivity(left) and Rework(right) Percentage of Total Work[2]

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[1] *Disital Data-Collection Device for Construction Site Documentation,* L. Y. Liu, Computing in Civil Engineering, ASCE, New York, NY (2), 1287-1293, 1995

[2] Source from above research paper

This lower productivity is mainly caused by the following reason. The field workers needed more time to study and navigate CAD documents on site with a relatively small screen.

Rework required was significantly lower in the projects using tablet and wearable computers than using paper documents. In the case of paper documents, 4.15% of total project time was spent engaged in rework. In the tablet case, 0%, and in the wearable case, 1.38%. This great reduction in rework shows extreme accuracy and clearance in information using tablet and wearable computers at the point of work site.

According to those experiments, the on-site application of innovative communication technologies such as tablet and wearable computers showed an improved performance in design and construction collaboration. The slight reduction in productivity is likely to occur whenever the users need an adoption time for a new technology. The important point is that those technologies enhance the level of accuracy and swiftness in information communicated between fieldworkers on-site and off-site collaborators in building design and construction. Consequently, the design and construction team could reduce the risk of errors and rework by ensuring that everyone in the team is working with the most current drawings and other documents.

Another strong advantage of those tablet and wearable computers that I like to emphasize is their mobility. The most significant characteristic of recent information technology is wireless accessibility and mobility. Since most of construction projects require constant exchange of information regardless of place, it is greatly encouraged to keep up with newest wireless technologies if they wish to remain innovative and competitive in the construction industry.

2.1.2. Constructability Analysis Program

Constructability characterizes the feasibility and simplicity of construction of a given design concept. It is determined by all design decisions with impact on the construction process.[3] Fast and precise constructibility analysis in the early design phases benefits all members of a project team by improving the performance of construction operations and decreasing construction costs. Currently, constructability reviews are performed manually by analyzing 2D or 3D drawings. This manual process is time-consuming and possible to make errors and does not identify the cost implications. Hence, the implementation of an automated constuctability analysis system is needed to provide immediate and specific feedback to designers on how the constructability problem impacts construction.

In this section, I describe a recently developing on-line computer program that provides automated constructability and cost analysis. At the end, I like to

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[3] *Constructability Analysis: Machine Learning Approach,* Mirosaw Skibniewski, Tomasz Arciszewski, and Kamolwan Lueprasert, Journal of Computing in Civil Engineering, Vol. 11, No. 1, pp. 8-16, January 1997

emphasize on how this innovative technology will affect the integration of design and construction knowledge.

- A Case Model

Recently, there is a research on developing models for identifying constructability problems and predicting the corresponding implications and associated costs.[4] This on-line system provides feedback to designers on the constructability of a given facility design and the corresponding cost of constructability problems. The system's approach consists of three steps: (1) Identify Constructability Features, (2) Identify Construction Implications, and (3) Calculate Costs.

The first module identifies design-relavant constructability problems in the input product model and instantiates them as constructability features. The system analyzes the input product model and creates project-specific constructability features. The second module identifies the construction implications for the project-specific constructability features. Lastly, the third module calculates the costs of constructability features based on the associated construction implications. The system supports multiple users including designers, estimators, and project teams.

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[4] *Providing Cost and Constructability Feedback to Designers,* Sheryl Staub-French, Research paper from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, 2003, Hawaii

Through this case example, I outlined new formalized mechanisms that can model the cost implications of different types of constructability problems. This innovative system will contribute to improve the efficiency of the constructability review process by reducing a significant amount of time due to the manual process. Moreover, this system can help the designers to identify specific design conditions that impact constructability and construction costs early in the project delivery process.

2.2. Interoperability

Architecture, engineering, construction, and facilities management (AEC/FM) are very much dependant upon information technologies. Those participants in a construction project need to share information very effectively and there has been a significant progress in research and development in linking and sharing of information throughout the AEC/FM industry. Interoperability, the ability for information to flow from one computer application to the next throughout the lifecycle of a project, is one of the major themes of research and development in that area.

Interoperability relies on the development and use of standardized information structure throughout the highly fragmented AEC/FM industry. For this standardization issue, I like to look at two emerging interoperability techniques; web-base collaboration and model-based approach. I will describe some prototype systems for each approach and evaluate how they could provide the solution to the standardization problem.

2.2.1. Web-based System

Since most of existing EDI (Electronic Data Interchange) was often developed and used only within an organization, linking and sharing knowledge and information between different organizations in construction projects has not been efficient. The currently developed Web-based EDI model can provide the ability to exchange documents and share construction data among the participants and the documents can be easily created, received, dispatched, stored, and removed through the web.

- Application of XML

Construction field documents are classified into various types: management, resource, safety, environment, public service, progress, architecture, subcontract, techniques, quality etc. XML is a standard document form of W3C (World Wide Web Consortium) and can be operated in construction document very efficiently.[5] It enables data exchange (e.g. information retrieval, information search, and information abstraction) in database and is compatible in all areas.

The most significant merit of XML is that it is independent of hardware and software that it can be easily exchanged with a participant who are in poor IT environment. For example, a sub contractor, who doesn't have a required IT system, can receive documents via the Internet if the sender convert XML document to HTML document.

- XML/EDL Model

Web-based XML/EDI model has a central DB that manages users, format,

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[5] *Web-based Electronic Data Interchange Model to Improve the Collaboration of Participants in Construction Projects,* Hyun-Soo Lee, Sun-Ju An, Bo-Sik Son, Myung-Houn Jang, and Yoon-Ki, Choi. Research paper from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, 2003, Hawaii

and version systematically. Central DB can manage all the different forms of documents by version control. XML/EDI model consists of viewer module, information management module, DBMS (Data Base Management System), and user interface. A user can provide document with user interface and the document distribution is conducted in the DB. Needed information is sent to users by information management module and DBMS also provides related information to view module.

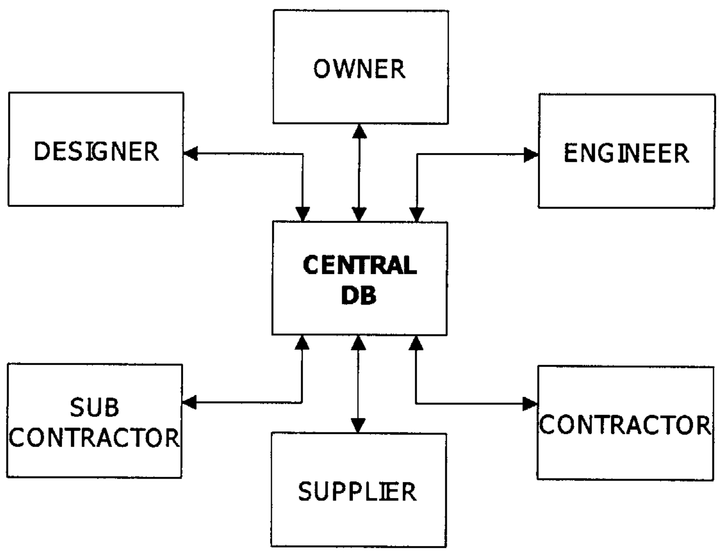

Figure 2-3 Document exchange with central DB

2.2.2. Model-based Interoperability

While web-based systems are already implemented for full-scale use, model-based approach is just beginning to increase its practical adoption. Model-based system can provide as a framework for collaboration, coordination, and information sharing among a variety of computational systems used during the project life cycle. In this system, all information is structured around an object-oriented data model of the project. The standardization of the models used in those various computational systems is an important requirement for interoperability. The Industry Foundation Classes (IFC) aim to define standards for model-based systems.

There are two prototype model-based systems.[6]

- A falsework design system, which helps in the layout, design, and planning of heavy falsework systems for elevated highways. This system is based on a CAD platform
- A general purpose project browser, which can import a variety of project information – product information, costs, schedules, documents, resource information etc. – and interlinks them all within a CAD-based explorer environment

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[6] *A Model-Based Approach for Implementing Integrated Project Systems*, M. Halfawy and T. Froese, 9th International Conference on Computing in Civil and Building Engineering, Taipei, Taiwan, Vol. 2. pp. 1003-1008, April 3-5, 2002.

- Automated Integration

Since large percentage of AEC/FM information is stored on text document (e.g. contracts, specifications, meeting minutes, change orders, field reports, requests for proposal, and etc.), methods for integrating text data in model-based systems become very important. In order to support this integration, standards, such as IFC framework, are used to reference documents and related model objects. Currently, there are no formal methods to automatically achieve this integration.

Since the number of text documents and objects created in model-based systems in AEC/FM projects are significant, the required time and effort to link between text documents and project model objects would be enormous if it is done manually. Recently, a methodology for automated integration was explored.[7] This automated integration methodology consists of three main steps.

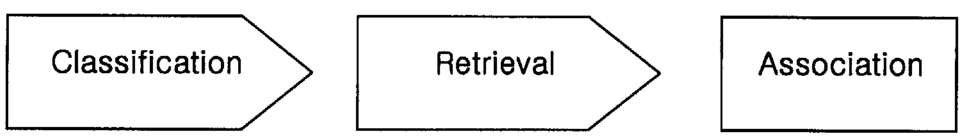

Figure 2-4 Three steps in automated integration

[7] *Integration of Construction Documents in IFC Project Models*, Carlos H. Caldas and Lucio Soibelman, Research paper from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, 2003, Hawaii

First, documents are classified according to the classes defined in the IFC model. Next, the documents that are related to the selected objects are retrieved. Last, relevant retrieved documents are linked to related model objects. A prototype of a model-based system using this methodology was developed and some experiments demonstrated a higher precision in linking documents.

- Standardization and Further Development

There has been a standardization issue on the data exchange languages throughout the AEC/FM IT community and the International Alliance for Interoperability (IAI)[8] has been developing the IFC standards to support standardization in interoperabiliy. Almost any type of AEC building projects data information such as parts of a building, the geometry and material properties of building projects, project costs, schedules, and organizations, ect. can be mapped into IFC data files which provide a neutral file format. In this way, various AEC/FM computer applications can efficiently share and exchange project information.

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[8] A global coalition of industry practitioners, software vendors, and researchers over 600 companies around the world

2.3. Industry Wide Applications

Many industries throughout the world use the Internet as a channel to communicate or to exchange information more effectively. In construction industry, the Internet could be used as an efficient tool for communication to bring together all the diverse project participants and project teams all over the world. This increasing availability and the usage of the web-based systems has brought about change in the construction industry to improve quality, competitiveness and profitability and provide better relationship with clients and suppliers. In this section, I describe how web-based project management systems and other organizational systems are used to fulfill the above accomplishments in the construction industry. I also highlight benefits gained by the organizations and valuable lessons learned.

2.3.1. Web-Based Project Management Systems

Web-Based Project Management System (WPMS) has initially developed from the notion of how the Internet and its associated technologies can be used to manage construction projects. The system enhances the process of exchanging, sharing, and managing project information among the project teams throughout the project lifecycle.

Alshawi and Ingirige provide a comprehensive definition for WPMS.

"WPMS is an electronic project-management system operated through the internet. The system provides a centralized, commonly accessible, reliable means of transmitting and storing project information. Project information is stored on the server and standard Web browser is used as a gateway to exchange these information, eliminating geographic and hardware platforms boundary." [9]

Let me summarize some of the most significant features of WPMS. This system can:

- Speed up the distribution of documents and the communication between clients, contractors, and subcontractors
- Allow the design team to mark up and comment on drawings online during the process of request for information and approval
- Provide an environment where the diverse participants can perform collaboration via the web

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[9] *Web-Based Project Management,* M. Alshawi and B. Ingirige. A report on web-enabled project management, University of Salford, UK, available at (http://www.extranetnews.com/web%20enabled%20project%20managment.pdf), 2002

- A Recent Survey

Currently, a large number of AEC firms rent or lease a completely developed WPM software from an application service provider (ASP) for a usage fee. I found this trend from a survey that was carried out by "Construction Plus" (Http://www.constructionplus.co.uk) on 1500 British Construction projects on the usage of WPMS.

Company	WPM Software	No. of Projects	Users
4Projects.com	4Projects	185	2,500
Architec Ltd	architec.net	10	250
Atkins	iProNet	200+	1,820
Bentley	Viecom	100s	100s
Bidcom	ProjectNet	96	2,698
Bricsnet	ProjectCenter	20	200
BIW Technologies	Information Channel	350	5,547
BuildOnline	ProjectsOnline	30	800
Buzzsaw	ProjectPoint	N/A	N/A
Causeway	ProjectLink	N/A	N/A
Enviros Ltd	Business Collaborator	30	4,000
Framework Technologies	ActiveProject	6	150
Hummingbird DOCS Fusion	Hummingbird DOCS fusion	120	6,000
Meridian Project Systems	ProjectTalk	N/A	N/A
OpenText	LiveLink	250+	100+
Sarcophagus	the project	50	1500
Web4	WebWorks	8	50

Table 2-1 UK Project Collaboration Survey Results

This survey shows that there are about 20 software vendors offering WPMS in the UK, in ASP format and they are supporting over 1500 projects with 25,000 users.

- Analysis and Future directions

I like to emphasize on the advantages of this new technology within two areas: industry wide and organization wide. First, in AEC industry, all project members could benefit from WPMS by obtaining a snapshot of the project as it is built and sharing project information throughout the entire supply chain.

Project managers could improve their abilities to manage project documents, and their workers. Clients could easily see the project's progress and ensure that the projects are completed with quality and within the schedule and budget. Contractors could improve their overall construction processes by cumulating their experience of working collaboratively.

Secondly, WPMS could provide some major benefits within the organizations. Especially for small and mid-sized AEC firms, the option of rent/lease a completely developed WPMS from an ASP greatly reduces the initial investment and overhead cost, but still they can maintain technological advantage. Therefore, it is a very suitable solution for small or mid-sized AEC firms that can not support the huge amount of set up cost for in-house IT systems and networking infrastructure.

2.3.2. Enterprise Resource Planning (ERP) Systems

Enterprise Resource Planning (ERP) systems are packaged business software systems that integrate and automate many of the organization's business processes such as accounting, finance, human resources, manufacturing, procurement, and distribution, etc. In addition, they also connect the organization to its clients and suppliers throughout the product or process life cycle.

The followings are benefits and disadvantages of implementing the ERP systems.[10] Benefits:

- Provide an integrating working environment.
- Enable automation
- Availability of information from field level to the management level
- Integration in applications in any departments
- Flexibility and facility to standardizing process or to accommodate changes and globalization.
- Achieve balanced people, process and technology changes across all areas.
- Apply planning and program management practices throughout the program life cycle of a project.

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[10] *Implementation Of Enterprise Resource Planning (ERP) Systems In The Construction Industry,* Syed M. Ahmed, Irtishad Ahmad, Salman Azhar, and Suneetha Mallikarjuna. Research paper from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, 2003, Hawaii

Disadvantages:

- Large amount of implementation cost and time. It can range from some hundred thousands of dollar in small companies to a billion dollar for large multinational companies (these numbers include training and consulting). Total implementation time can take up to 10 years.

- Delay on return on investment. The benefits of ERP may not be shown until after companies have had it running for some time.

In this section, I like to focus on the suitability of the ERP systems for the construction industry through investigating some simulation models and questionnaire survey.

- Market Study

The study about how U.S. and European firms currently use Enterprise Resource Planning (ERP) systems and how its use will change over the next few years was conducted by ML Payton Consultants in 2000.[11] Study results showed that the market is showing steady growth and most of the Fortune 1000 companies have already implemented ERP systems, so vendors are targeting smaller mid-level markets such as construction industry. Among the top vendors, SAP has

[11] *Use of Enterprise Resource Planning in the Construction Industry –Summary of Findings*, ML Payton Consultants, On-line; http://www.mlpayton.com/pages/summaries.html, 2000

been the market leader, although its share has been declining in the past few years.

Most significantly, the study tells you that in order to remain successful, companies will have to implement ERP in some form. Since there is no standard methodology for implementation so far, each company should find the best approach to implementing ERP systems for its business needs.

- ERP Systems in Construction Industry

Since construction is a highly fragmented industry, it is very important to communicate efficiently with other associated businesses such as material and equipment suppliers, vendors, subcontractors and clients. For this reason, ERP systems can provide huge advantages to construction companies. More specifically, construction companies can use ERP systems to (ML Payton, 2000):[12]

- Improve responsiveness in relation to customers
- Strengthen supply chain partnerships
- Enhance organizational flexibility
- Improve decision making capabilities
- Reduce project completion time
- Lower costs

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[12] See the previous footnote

These advantages show that ERP systems can be a powerful tool for business improvement. Yet, there are very few construction companies that have implemented the system so far. This is mainly because of that the implementation requires a large investment in time, money and resources.

- Simulation Models

Many construction firms have computer based material management systems (MMS). ERP systems can be used to integrate MMS with external computer systems to perform functions related to design, project scheduling and accounting, improving cost and document processing cycle time. A simulation model to implement ERP in the MMS was created by Lee et. al. (2002).[13] He implemented the model in four distinct activities, which are application integration, internal integration, external integration, and automation. As a result, the ERP system shortened the duration of almost all of the activities, specifically, procurement cycle by approximately 80%, through automating most of the repeating transactions, and by reducing manpower to perform the tasks. Implementing ERP systems in the materials management area has measurable benefits in all other areas, which interface with the material management module.[14]

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[13] *Simulation Modeling by Enterprise Resource Planning implementation in Medium Sized Corporation*, S. Lee, A. Arif and D. Halpin, Proceedings of First International Conference on Construction in the 21st Century (CITC-2002), Miami, Florida, pp 663-670, 2002

[14] Quoted from above journal

Another case model study was conducted by Connor and Dodd (2000).[15] They conducted a survey to evaluate the functionality and adequacy of the R/3 (a ERP software solely designed for the construction industry). R/3 provides 15 functions which are: unit price racking, job cost reports, labor cost report and work hour forecasting, change order cost tracking, work breakdown structure model, project conceptual/milestone schedule, detailed activity precedence network, project schedule reports, short interval planning, purchase order development and issuance, monitoring of change orders, rework, and back-charges, management of contractor retainage, tracking and documenting percentage of physical completion, field warehouse inventory management and warehouse inventory reorder management.

However, there are some functional gaps between R/3 and other existing systems. Other software systems can be used to supplement R/3 in the areas of facility configurations, design and as-built configurations, technical specifications, physical interference detection, facility walk-through simulation and equipment selection and scheduling assistance. Therefore, it is strongly recommended that the construction professionals work with the existing ERP software vendors to reduce those functional gaps of R/3 and provide more suitable ERP system for construction firms.

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[15] *Achieving integration on capital Projects with enterprise Resource Planning Systems*, J. Connor and S. C. Dodd, Automation in Construction, Vol 9, issues 5-6 pp 5515-524, 2000

- Questionnaire Survey

A questionnaire survey on the suitability and the implementation status of ERP systems in contractor firms was conducted.[16] Since many small and medium sized contractors are still not familiar with ERP, only 12 large companies like Bechtel, Bovis Lendlease, Turner Construction, etc. were able to share their experiences.

The followings are summarized findings.

- Knowledge about ERP systems:
  - 92% (11 out of 12) of the respondents were aware of the ERP systems in general and 33% (4 out of 12) of the respondents indicated that they were earlier contacted by an ERP vendor about the possible implementation of ERP systems in their organizations.

- The system's successfulness:
  - 58% (7 out of 12) of the respondents indicate that the ERP systems will be beneficial for their organization
  - 42% (5 out of 12) of the respondents are either "not sure" or have the opinion that ERP will "not work" in their setup.

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[16] Conducted by Syed M. Ahmed, Irtishad Ahmad, Salman Azhar and Suneetha Mallikarjuna, Florida International University, available on website (http://www.eng.fiu.edu/cm/erp), 2002

- Expected benefits (they responded in the sequential order):

  1. Improve decision making capabilities
  2. Improve responsiveness to customers
  3. Enhance organizational flexibility
  4. Strengthen supply chain partnerships
  5. Reduce project completion time and cost

- On the satisfaction level about the performance of ERP systems:

  - High 8% (1 out of 12)
  - Moderate 33% (4 out of 12)
  - Low 42% (5 out of 12)
  - No response 17% (2 out of 12)

- Other recommendations:

  - 42%(5 out of 12) respondents indicate that their current ERP systems are not fully integrated and they need further customization.
  - 83%(10 out of 12) respondents recommended the need of extensive training programs to fully understand the functionality of ERP software to enjoy their benefits. Majority of these respondents pointed out that the training must be started with the top management and then on the middle and lower management respectively.

- Analysis and Future Directions

On the basis of case model studies and questionnaire survey, it can be informed that a majority of contraction organizations are aware of the ERP systems and they think that the implementation of ERP systems could benefit their organizations. Yet, very few organizations have implemented an internal system so far mainly because of the huge amount of initial investment in time, money and resources. Overall, while companies are, at some level, satisfied with the performance of their ERP systems, they requested more development from the existing ERP vendors to meet the unique needs of the construction industry. Therefore, the ERP software vendors must work with the construction organizations to provide more suitable ERP systems for construction firms, for example, upgraded R/3 system with less functional gaps. In order to gain full advantages from the ERP systems, a consistent effort on investment and skill training is strongly recommended to the construction organizations.

Chapter 3. Knowledge Management Strategy

3.1. What is Knowledge Management?

From my concept, the term of knowledge management refers to as the process of capturing or creating important information and transforming it into useful knowledge so that the stored knowledge could be disseminated within an organization. For this reason, knowledge management can be a strategic weapon to organizations wishing to remain competitive. The approaches may vary from one organization to another, but often they follow such steps as:[17]

1. Creating repositories of information about best practices
2. Setting up networks for transferring information between employees who interact with customers and those who create the product
3. Creating formal procedures to ensure that lessons learned in the course of a project are passed along to others doing similar tasks.

Recent developments in information technology allow organizations to follow those steps more efficiently. Organizations can capture, store, analyze and retrieve information using technologies such as data mining, advanced decision support tools, intranets, and decision indexing. In the following section, I explain

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[17] *Do we know how to do that? Understanding Knowledge Management*, Harvard Business School Cases, Case #U9902A, 1999.

detailed characteristics of knowledge management (KM) and examine the relationship between KM and information technology. At the last section, I investigate how other sectors have developed and established KM strategies for their organizations.

3.1.1. Characteristics of Knowledge Management

Knowledge is made up of both tacit and explicit components (Nonaka & Takeuchi, 1995).[18] Tacit knowledge is highly personal, developed from experience, is hard to formalize and therefore difficult to communicate. Explicit knowledge is formal and systematic. It is therefore easy to document, communicate and share.[19] In order to examine the relationship between KM and IT, we have to look at the term of explicit knowledge. For the explicit knowledge, those valuable knowledge within an organization can be codified and easily stored, retrieved, and transferred by using information technologies. If project teams or individuals execute construction projects without conducting post-project reviews and documenting lessons learnt, both team and individual learning experiences cannot be disseminated. These knowledge management processes can be improved by the development of IT tools. For tacit knowledge, regular executive board meetings, mentoring program (senior

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[18] *The Knowledge-Creating Company,* I. Nonaka and H. Takeuchi, Oxford University Press, 1995

[19] *Knowledge Management Strategies: Learning From Other Sectors,* Patricia Carrillo, Herbert Robinson, and Francis Hartman, Research paper from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, 2003, Hawaii

managers with juniors), social meetings, and lessons learnt critiques can be the mechanisms to transfer the tacit knowledge of employees.

3.2.2. Learning From Other Sectors

Unfortunately, like in other industry, some construction companies have embarked on KM programs without thinking through their objectives and the consequences (Storey and Barnet, 2000).[20] Therefore, we should investigate how other companies have developed KM strategies. In this section, I summarize two case studies[21] comparing the different approaches adopted for knowledge management between UK construction organization and Canadian oil and gas organization.

- Company A

Company A is a UK-based international housing and development group with over 8,000 employees and operations in North America, South East Asia and Africa. The organization has a turnover of over £2,000M ($3,200M US) and gross profit of over of £200M ($320M US) (2001 figures).

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20 *Knowledge Management Initiatives: Learning from Failure,* J. Storey and E. Barnett, Journal of Knowledge Management, 4(2), 145-156, 2000

21 *Knowledge Management Strategies: Learning From Other Sectors,* Patricia Carrillo, Herbert Robinson, and Francis Hartman, Research paper from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, 2003, Hawaii

A knowledge manager was appointed in 2000 to develop and implement the company's knowledge management strategy. There are a number of knowledge management initiatives taking demonstration projects to show the benefits of KM. A number of initiatives also promote the use of electronic newsletters and promotional handouts. The company is involved in a number of research projects focusing on KM in construction and employees can share the information on their research projects or from other research papers through the company's intranet. This system initially established the structure for dissemination of best knowledge within the company. It has now been significantly improved by restructuring it more user-friendly.

- Company B

Company B is considered one of the leading integrated energy companies based in Canada. The company specializes in the mining and extraction of crude oil, the exploration, development and marketing of natural gas and the development of renewable energy sources. The company employs 3,300 personnel and has an annual revenue of around $2,500M US (£1,600M) and Return on Capital Employed (ROCE) of 17.9% (2001 figures).

The company considers KM as the ability of people in the organization to access the expertise held by the organization. The decision to take KM seriously came from the senior management group and has been filtered downwards to all levels of management. A multi-disciplinary working group, drawn from across the organization, is then tasked with solving the KM problem within a stated period. The company justifies how the KM efforts impacts on the corporate goals and publicizes it on the company portal to ensure that all users understand the importance of KM to the organization. The KM focus is on codifying knowledge using a web portal.

- Lessons Learned

Both companies focused IT-facilitated sharing of knowledge without considering much of the tacit knowledge management mechanisms such as mentoring, tutoring, training etc. On this point, we should recognize that KM is concerned with managing both tacit and explicit knowledge. Using IT systems to manage only explicit knowledge provides a partial solution to KM strategy. I like to emphasize that organizations should develop the best ways to capture and store the tacit knowledge as well as explicit knowledge using information technologies. This process may cause some conflicts within the organizational structure. Senior managers would not want their roles to be decreased due to the implementation of KM system in the organization. Hence, the impact of IT system on the organizational structure and culture should be carefully considered.

3.2. Knowledge Management for Construction Industry

According to Drucker (1993), the whole world has entered in a society which is based on knowledge and information.[22] Actually there has been a need to improve the knowledge management within an organization in all industrial sectors including the construction industry in the last few years. Managing knowledge is becoming more and more important to the construction industry due to the unique characteristics of its projects such as multi-disciplinary teams, temporary team members, heavy reliance on experience, the one-off nature of the projects, tight schedules, limited budget, etc.[23] In addition, knowledge management can be a strong asset for some types of procurement such as partnerships due to the nature of the long term relationships between the members of the supply chain.

Although many mechanisms have been developed for managing knowledge within construction industry, there is still very little understanding of the best ways to capture, store, and transfer knowledge. In this section, I look at the development of a detailed information architecture for structuring the knowledge that organizations can capture, analyze, and retrieve within the construction industry. A discussion of the challenges related to the model development and implementation are also addressed.

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[22] *Post-Capitalist Society*, P. Drucker, Oxford, 1993

[23] *Knowledge Management for Sustainable Construction: The C-SanD Project*, M. M. A. Khalfan, N. M. Bouchlaghem, C. J. Anumba, and P. M. Carrillo, Research paper from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, 2003, Hawaii

3.2.1. Knowledge Management Issues in Construction Industry

This section presents some initial project findings and discusses the knowledge management issues identified during the case studies undertaken within construction projects.

- Categorization of Knowledge Management Approaches

According to Venters (2002), a number of authors have set up categorizations of knowledge management approaches.[24] The two main categories are the functionalist perspective and the interpretive perspective.

In functionalist perspective, knowledge is considered as an "object" existing in a number of forms and locations so that it can be valuable asset to organizations. In this approach, knowledge can be captured and codified into information and documents, and cumulated as an asset of the organization. As I mentioned in the previous section, such an approach requires very high support from the development of information technology.

In interpretivist perspective, knowledge is considered as socially constructed. In other words, knowledge is constructed from individuals' experience and social practices. In this approach, the focus of knowledge management is not on mapping, storing and disseminating an object but on

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[24] *Literature review for C-SanD: Knowledge Management*, W. Venters, LSE, 2002

supporting and creating many social activities where individuals' knowledge is shared such as communities of practice. This requires another important role of technology, which is to support and create social activities, as a knowledge management solution within the construction industry.

- Difficulties in Knowledge Management

Many practitioners have acknowledged the difficulties in current approaches to managing the knowledge in construction activities. I narrowed them down to two main streams of difficulties. One is process related and the other is individual related.

First, the process of creating knowledge during the project is very complex. Usually, knowledge is captured during a project and archived at the end of a project. Through this process, the knowledge gained can be poorly organized or buried in details. It requires complex processes to track the thousands of messages, phone calls, memos, conversations and all other project-related information. Hence, it is difficult to organize and compile useful knowledge at the end of a project. The problems related to the feedback and learning process also include time limits to conduct project review, no formal feedback loops, no formal methods to capture best practices of the design and construction of a facility, etc.

Secondly, much of construction knowledge resides in the memories of the individuals. Since people frequently move from one project to another, it is difficult to track the people who were involved in making decisions and capture the intent behind decisions. In addition, knowledge management process can be resisted by the individuals who are likely to have changes in their roles.

- KM for Small and Mid size Construction Companies

In general, small and medium size organizations are knowledge users rather than knowledge producers. These organizations usually depend on individuals' own knowledge during the design and construction processes. Since these organizations cannot afford any sophisticated internal systems, they need to develop local networks to access to external knowledge providing systems.

3.2.2. Organization Based Information Architecture

Most information models developed previously have focused on the data exchange during the design and construction of a project. Yet, these previous efforts have not focused on the knowledge modeling processes needed to support the effective operations of an organization. Therefore, there is a need to expand upon these previous modeling efforts to develop a model that supports to manage the extended knowledge (e.g. knowledge about multiple projects, other participants, contracts, and environments).

For this reason, a prototype of KM structure model, the Organization Based Information Architecture (OBIA), has been developed.[25] This information model has been developed through the detailed analysis of the strategic decision-making process. This decision focuses on a company's evaluation of potential projects and the determination of whether to pursue the project. In order to make this decision, an organization must consider a wide range of knowledge within the company. This scope of knowledge includes on the owner, their competitors, their potential partners, the project environment, the proposed contract, the scope of services or processes required, and the facility to be constructed. The OBIA supports to determine these strategic level decisions within construction organizations. This model breaks down an organization's knowledge into five main categories: 1)

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[25] *An Architecture for Knowledge Management in the AEC Industry*, John I. Messner, Research paper from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, 2003, Hawaii

Organization information, 2) Commitment information, 3) Process information, 4) Environment information, and 5) Product information. These categories are shown in Level 1 of the information architecture (see Figure 3-1).

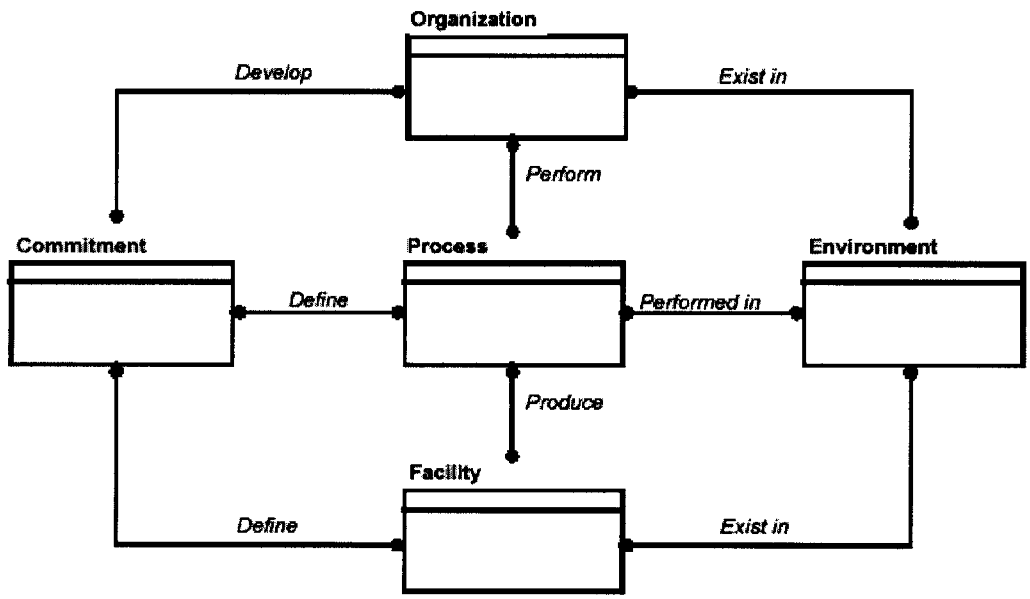

Figure 3-1. Organization Based Information Architecture (Level 1)[26]

Each main category then is broken down again into 1 or 2 levels of additional detailed categories. For example, organizations are further categorized into organizational goals and organizational resources. Then the organizational goals are defined by types of goals and organizational resources are defined by types of resources.

[26] *An Architecture for Knowledge Management in the AEC Industry*, John I. Messner, Research paper from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, 2003, Hawaii

One considerable feature in this OBIA model is that this model can capture knowledge related to the environment. Although knowledge related to the environment is critical within a construction organization, it has not been emphasized by previous modeling efforts. Since the construction industry is a project-based industry, knowledge about the environment in the location of a project must be captured and retrieved to expect better performance in an unfamiliar environment. The environment is divided into the following six types: physical, political, legal, economic, cultural, and resource.

This information framework provides a standard structure for storing and managing knowledge within the construction industry. An organization can use this standard structure to develop knowledge management tools within an organization. The structure also provides the ability to share knowledge between organizations. In other words, this knowledge management structure will allow companies to create standardized applications to share knowledge within an organization and between organizations.

3.3. KM Strategy within an Organization: Using System Dynamics Model

Using a system dynamics model, I explore the KM strategy in construction industry in terms of invisible (organizational impact) effect as well as well-known visible (money) effect. Based on this, I capture some feedbacks of KM on the organizational aspect.

3.3.1. Knowledge Management Impact on Construction Industry

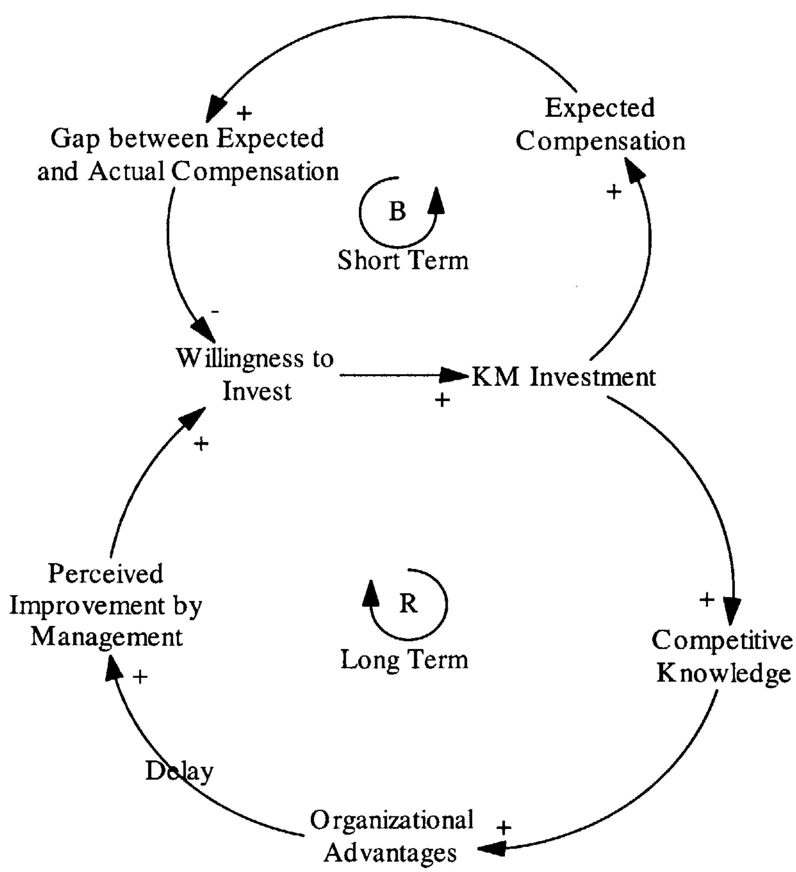

Figure 3-2 Basic Causal Loop Diagram for KM Strategy

In my mental model, I captured two general (one positive and one negative) loops in the Knowledge Management investment cycle. In the positive loop, since there is a time delay before the organizational advantages are perceived by the management, I consider it as a long-term strategy. On the other hand, short-term compensation is not expected to be good enough for the organization in terms of profitability through the negative loop.

Decision makers in the construction industry are aware of the existence and the controversy of these two loops. Therefore, they are unsure about how much profit KM will generate and when the returns will be acquired because it requires a long period to evaluate KM success in the organization.

However, I believe that KM needs to be evaluated by its impact on the organizational strategies as well as this monetary term. This is based on the hypothesis that the project success should be measured by organizational success view, rather than the project itself. The examples of some important impacts on the organizational success are creating strong relationship with clients and the proficiency of new innovative technology, which is acquired by the project success. In this sense, in terms of KM evaluation, how KM contributes to the organizational success as well as to the project itself is equally important.

3.3.2. The Impact of KM on the Organizational Strategy

Many construction companies set their organizational strategy based on their experience of previous projects. However, I like to show in my model that organizations must choose projects based on their strategic goals set by KM.

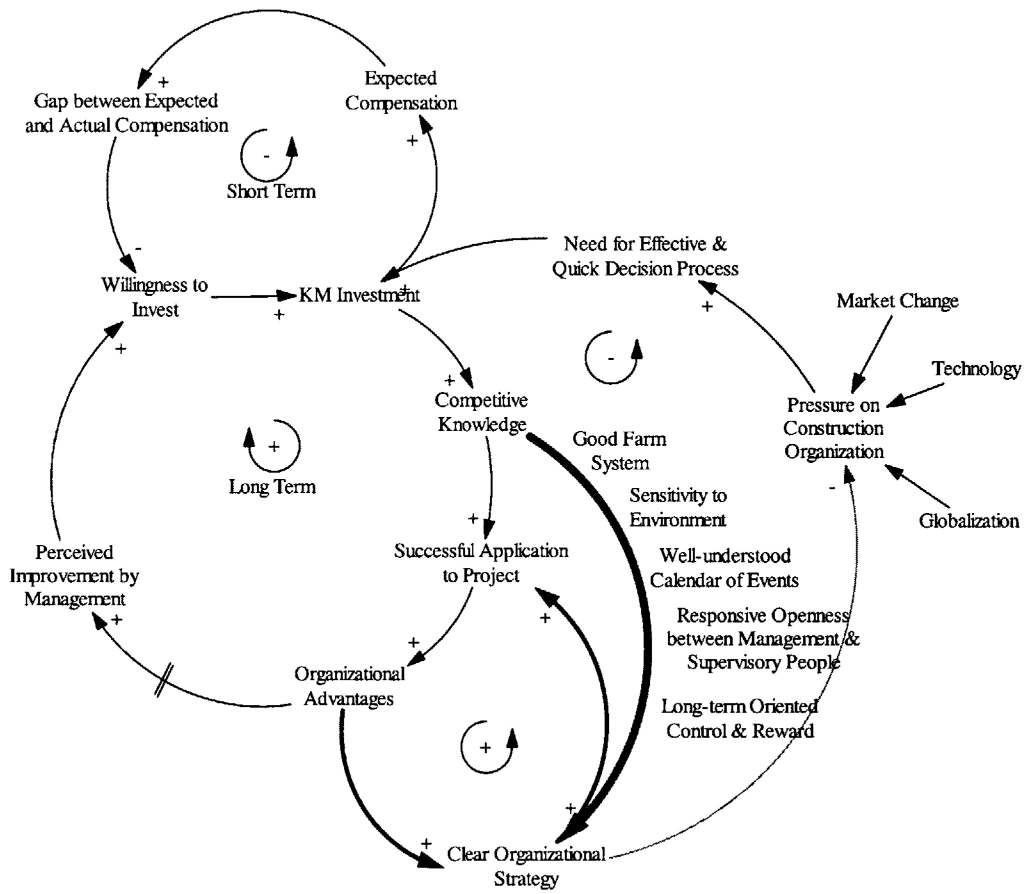

Figure 3-3 Causal Diagram for KM impact on Organizational Strategy

In this model, a construction organization gets constant pressure from market change, technology innovation, and globalization. Then, KM investment can be a solution for this need for an effective and quick decision process. This KM strategy leads to the clear organizational strategies through good farm system, flexible to environment, well-understood calendar of events, responsive openness between management and supervisory people, and long-term oriented control and reward. Once the organizational strategy is set, it will apply on the project selection processes and successful application will increase organizational competitiveness. This iterative process becomes a strong positive loop for the organizational strategy and eventually, all these advantages came from KM investment.

To deal with the rapid change of business environment, knowing the industry trend and which projects to pursue is very important to make an organization competitive. That is the exactly what KM can do for the decision making process in the construction industry as an organizational strategy.

Chapter 4. Challenges for Adoption of IT in Construction

4.1. Industrial Barriers

One of the oldest issues in the literature on the adoption of technological innovations is whether diffusion is driven more by technology-push than by demand-pull mechanisms (Mowery and Rosenberg 1979, Nam and Tatum 1992).[27] Technology enthusiasts, academics, and software companies typically assume that technology-push governs the adoption of innovations in construction industry, while industry professionals concern very much on the practical obstacles to adoption of innovations. In previous chapters, I described the advantages of technology by focusing on the perspectives of technology enthusiasts and academics. In this section, I examine how industry professionals view the impact of innovative technologies and what they consider as the industrial barriers.

4.1.1. Who Benefits from the Savings?

Although there are plenty of technology tools available that can provide sufficient improvement to the construction processes, the pace of adopting those technologies seems relatively slow in the construction industry. Why aren't they

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[27] *The influence of market demand upon innovation a critical review of some recent empirical studies*, D. Mowery and N. Rosenberg, Research Policy, 8(April), 103-153, 1979 / *Strategies for technology push: lessons from construction innovations*, C. H. Nam and C. B. Tatum, J. Const. Engr. and Mmgt, 118(3), 507-524, 1992

used? Because, in practice, people are unsure or skeptical about the cost savings from using the tools.

This problem can be demonstrated in some particular types of contract. If we look at the cost plus a fee contract type, a construction management firm gets a fixed fee without any incentives on the cost savings. The firm can generate significant cost savings in the project by using high tech, innovative tools implemented in the organization. However, the savings are not passed on to the firm, but rather to the client. The construction management firm may win more projects from its competitively low cost, but the managements consider that the return is relatively small comparing to the huge amount of their investment in IT.

Technologists argue that the adoption of technologies to a project would save owner's significant money in the life cycle of a project. However, an industrial professional argues that, in practice, the savings are small, they occur over a very long time frame, and usually they flow through to multiple departments in the Owner firm, so there is no integrating champion.[28] We can see this practical calculation in Figure 4-1.[29] This figure proposes a template for evaluating the actual impact of re-use of information on life cycle cost savings.

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[28] *Follow the Money: What Really Drives Technology Innovation in Construction*, John D. Macomber, Research paper from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, 2003, Hawaii

[29] A figure from above research paper

Illustrative Template Owner Cost in Millions	Plan & Design	Procure & Construct	Operate	Dispose	Life Cycle Sums
Duration of Phases	1 yr	2 yr	10 yr	1 yr	14 yr
Baseline Costs - Old way	10	100	1000	5	1115
PROPOSED ADDITIONAL COST					
Added cost to embed info which benefits later phases	2	3	2	0	7
PROPOSED BENEFIT					
Ability to use information from prior phase	0	5	15	1	21
Add to asset value	0	0	0	5	5
Total Benefit	0	5	15	6	26
Net Benefit of Info This Phase	-2	2	13	6	19

A negligible savings...

...over a very long time period

Figure 4-1. Life Cycle Cost Savings Template[30]

In this template, there are four major phases of the project: design, construction, operations, and disposition. There is a line for proposed additional costs to embed information in each phase. Here, the designer spends another $2mm to embed information. As a result, the contractor and operations teams benefit from the use of added information embedded during the design phase but the designer doesn't benefit. So why should the designer spend the money? In addition, the total savings from life cycle information costs are a very negligible benefit over a very long period of time, in relation to the entity's total cost.

Each firm in the construction industry will act against the overall benefit of

[30] See the previous footnote

IT to protect their own interests. The rational economic actors say over and over again, "I'm glad that you have technology that allows me to share my information with the team. But until I am paid to share—or at least not further exposed by sharing—why should I share?"[31]

4.1.2. General Contractor's Dilemma

General contractors do believe that information technology will increase their operational efficiency and reduce operational costs. The literature, however, discusses many industry factors that hinder the adoption of construction innovations (Toole 1998).[32]

- Cyclical sales, which increases the risk of high fixed costs.
- Vertical and horizontal fragmentation, which makes it difficult to integrate the value chain.
- Small size of firms, which makes it difficult to afford high capitalization costs.
- The craft nature of construction labor, which often resists changes.
- Low profit margins on total contract value, which increases the risk of high capitalization costs.

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[31] *IT Strategy For Construction Companies, A Pragmatist's Vision,* John D. Macomber, Leadership and Management in Engineering, Vol. 3, No. 2, pp. 94-99, 2003

[32] *Uncertainty and homebuilders' adoption of technological innovations,* T. M. Toole, J.Const. Engrg. And Mmgt, 125(4), 1998

- High management intensity, which prevents pursuit of strategic but non-urgent actions.
- Task characteristics that leads to uncertainty about whether innovations will function as expected.

These facts lead to an ambiguous position for the contractors whether to be enthusiastic adopters of IT by theoretical reasons or to be cautious consumers of IT by practical reasons. I would call it as 'General Contractor's Dilemma'. In this section, I summarize the investigation on ten large general contractors' perspective view on the impact of IT innovation on construction conducted by Toole (2003).[33] The investigation focuses on four specific issues. First:

- What specific technologies do contractors think will have the most impact on the AEC industry over the coming five years and what are contractors doing to benefit from these technologies?

Most interviewees indicated that there are four technologies which will have the most significant impact on the industry. First, web-based systems that integrate between companies will increase the efficiency of projects and allow better managerial and client oversight. They indicated that these systems will continue to be critical to their project management, estimating and marketing functions. They reported the most needed function from the system is the ability

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[33] *Information Technology Innovation: A View Of Large Contractors*, T. Michael Toole, Research paper from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, 2003, Hawaii

to transmit and record RFI, submittal data and installation progress. It was found that nearly all of the companies interviewed have invested in project collaboration software, such as Prolog, ConstructWare, or ActiveProject, but they don't mandate to use these systems in all of their projects. Rather, the use of those systems depends on the client's wishes, the type of project, and the geographic region. Several of the contractors replied that in some projects, they require their sub contractors to use the system.

Secondly, most interviewees indicated that mobile computing devices connected by high-speed wireless networks will significantly improve coordination on site. They stated that top two priority functions for those systems are the ability to enter payroll and job costing data while walking around the site and the ability to capture, transmit and retrieve drawings, documents and digital images. In order to take a full advantage from the systems, such as PDAs' and pocket PCs', they must be connected via high-speed wireless networks.

Thirdly, several firms reported that simulation and visualization software will become a powerful tool to coordinate design and installation, particularly involving mechanical systems. Currently, the use of such software involves architectural rendering used for business development purposes.

Lastly, most interviewees reported that web-based multi-media training systems will continue to be important. For the next decades, the employee training will focus on how to use the companies' IT systems.

- Has IT innovation caused significant changes within companies?

Nearly all interviewees stated that project managers and operational managers are now performing their tasks using a computer. The managers are able to involve in overseeing project processes very actively through the real-time project progress data. Several managers indicated that IT innovation brought significant changes in company's geographic operating units to become more tightly coupled and to increase the uniformity of processes and documents from operational data reporting to marketing proposals. Several interviewees indicated that although IT has substantially changed many operational processes and increased the amount of training that employees must receive, it has not substantially changed their company's organizational structure, hiring practices or performance evaluation system.

- What organizational issues affect the adoption of promising IT innovations?

Nearly all interviewees indicated that one of the biggest barriers to IT innovation was continuous pressure to justify the costs of new systems and capabilities. They indicated that the costs can be predicted with reasonable certainty but tangible benefits and the extents of potential users are difficult to predict. Most of participants stated that many of the older employees in their company were less eager to use and less capable of learning IT systems than younger employers.

- What changes in the business environment are driving or hindering IT innovation in contractors?

The majority of interviewees indicated that their own company's goals are to keep up with IT innovation and they regard IT as a powerful tool for increasing the efficiency of their operations, reducing costs, and increasing market share. However, most of them reported their business environment (e.g. clients, subcontractors, material suppliers and designers) as hindrances to IT innovations. They indicated that some of their clients are at least excited by the idea of real-time project data, while other clients are very effective consumers of such data. Since these clients vary widely in the quantity and type of data they want, it requires wide variation in firm's IT systems. None of the firms reported that subcontractors, material suppliers or designers were pushing them towards IT innovations. Most subcontractors cannot afford the time or the financial investment required for acquiring IT systems in house. Architects recognize the benefits of using an electronic project management system, but still resist using such systems due to liability and ownership concerns. Several firms reported that the custom integration to access to material vendors' databases to gain real-time pricing and inventory data requires expensive investment because of the wide variation of vendor systems.

4.2. Summary of Findings and Future Suggestions

In the previous section, the interviews of ten of the largest contractors provide insights on their use of information technology and how they view the future of IT in the construction industry. As I mentioned before, the dilemma set general contractors' position in between moving forward to the direction of the IT innovation and maintaining a watchful eye on many barriers to technological innovation. However, from the observation on the interviews, it seems that all of the managers focused on IT opportunities rather than obstacles. In this section, I summarize and evaluate the findings of previous investigations and then I suggest some ways that we can overcome the barriers of innovative technologies.

4.2.1. The Summary of Findings

The first issue from the findings of the investigations, which is perhaps the greatest barrier to change today, is that most players in construction projects have little financial incentive to experiment with expensive IT innovations with current delivery methods. In other words, margins in each construction phase are insufficient to attract individual firms to invest in better tools and procedures. Furthermore, the typical characteristics of construction industry, such as the fragmented nature and one-time project, do not generate sufficient motivation to invest in long-term innovations.

In addition, IT is being used to increase the speed, quantity, and quality of information flow between traditional channels within contractors' organizations, rather than being used to share information among all of the key participants involved in the construction of a project. It appears that there are challenges of adopting innovative technology for the benefit of many parties. Clearly, the chance of early adoption of such technology will depend upon the perceived benefit to each party using new technology.

4.2.2. Future Suggestions

To overcome such barriers to adopt innovations, I suggest two potential solutions. First, the new and innovative delivery models must be developed to motivate all project participants (from owner to general contractor, designer, subs, the crafts, as well as the manufacturers of building components) to invest in the IT innovations. The motivations must be financially linked. I suggest performance-oriented contracting models with a long-term alliance between firms and the owner who can immediately reward the parties based upon lower costs and shorter delivery times not solely upon a fixed fee in contract. In this contract model, the risks and rewards are shared to motivate all parties to enhance total project value, which obviously benefits to the owner. Multi-project alliances and shared investments in technology development will offer the potential for everyone to benefit.

Secondly, the industry must integrate across multiple participants. The existing players in the construction supply chain must change their competitive positions and share their specific knowledge on a real-time basis and in an integrated fashion. This transformation will require innovative tools through which to share knowledge and information on a functional, real-time basis.

While there are many barriers to transforming the industry, the potential benefits are extraordinarily compelling for practitioners and owners alike. Judging from other industry transformations, a few firms will lead it, some will follow, and the rest will fight it.[34]

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[34] *The AEC Dilemma-Exploring the Barriers To Change*, Peter Beck, Leadership and Management in Engineering, p31-36, April, 2001

Chapter 5. Conclusion

Based on this research, there are four information technologies that will have the most significant impact on the construction industry. First, mobile computing devices connected by high-speed wireless networks will significantly improve the communication between the fieldworkers on-site and off-site collaborators in building design and construction. The on-site application of technologies such as tablet and wearable computers enhances a significant level of accuracy and speed in information communication and provides great mobility to the site workers.

Secondly, an automated constructability analysis system will improve the efficiency of the constructability review process by reducing a significant amount of time that has been required through manual processes. Moreover, this system can help the designers to identify specific design conditions that impact constructability and construction costs early in the project delivery process.

Thirdly, the currently developed interoperability systems will provide the ability to exchange documents and share construction data among all the participants in project life cycle. The documents can be easily created, received, dispatched, stored, and removed through this system.

Lastly, the web-based operating systems that integrate between organizations will increase the efficiency of projects and allow better managerial and client oversight. These systems will continue to be critical to organization's project management, estimating and marketing functions.

Knowledge management is another area that information technologies can be applied in construction firms. Managing knowledge is becoming more and more important to the construction industry due to the unique characteristics of its projects such as multi-disciplinary teams, temporary team members, heavy reliance on experience, the one-off nature of the projects. In addition, knowledge management can be a strong asset for some types of procurement such as partnerships due to the nature of the long-term relationships between the members of the supply chain.

Although there are plenty of those technologies available, the pace of adopting such technologies seems relatively slow in the construction industry. Why aren't they used? First, people are unsure or skeptical about the cost savings from using the tools. Most players in construction projects have little financial incentive compared to their expensive and risky investment in IT innovations. Second, the fragmented nature of construction business environment acts as a barrier to IT innovations. To overcome such barriers to adopt innovations, I suggest two potential solutions. First, performance-oriented contracting models with a long-term alliance will motivate all project participants to invest in the IT innovations. Second, the industry must integrate across multiple participants so they can apply innovative tools through which to share knowledge and information on a functional, real-time basis.

The compelling IT strategies in construction industry with sufficient economic incentives will overcome the barriers and benefit each individual player in the whole supply chain. The combination between technology tools and business incentives will form the core of a strategic vision for IT in construction during the next decade.

References

Constructability Analysis: Machine Learning Approach, Mirosaw Skibniewski, Tomasz Arciszewski, and Kamolwan Lueprasert, Journal of Computing in Civil Engineering, Vol. 11, No. 1, pp. 8-16, January 1997

A Model-Based Approach for Implementing Integrated Project Systems, M. Halfawy and T. Froese, 9th International Conference on Computing in Civil and Building Engineering, Taipei, Taiwan, Vol. 2. pp. 1003-1008, April 3-5, 2002

Web-Based Project Management, M. Alshawi and B. Ingirige. A report on web-enabled project management, University of Salford, UK, Available at http://www.extranetnews.com/web%20enabled%20project%20managment.pdf, 2002

Use of Enterprise Resource Planning in the Construction Industry –Summary of Findings, ML Payton Consultants, On-line; http://www.mlpayton.com/pages/summaries.html, 2000

Simulation Modeling by Enterprise Resource Planning implementation in Medium Sized Corporation, S. Lee, A. Arif and D. Halpin, Proceedings of First International Conference on Construction in the 21st Century (CITC-2002), Miami, Florida, pp 663-670, 2002

Achieving integration on capital Projects with enterprise Resource Planning Systems, J. Connor and S. C. Dodd, Automation in Construction, Vol 9, issues 5-6 pp 5515-524, 2000

Do we know how to do that? Understanding Knowledge Management, Harvard Business School Cases, Case #U9902A, 1999

The Knowledge-Creating Company, I. Nonaka and H. Takeuchi, Oxford University Press, 1995

Knowledge Management Initiatives: Learning from Failure, J. Storey and E. Barnett, Journal of Knowledge Management, 4(2), 145-156, 2000

Post-Capitalist Society, P. Drucker, Oxford, 1993

Literature review for C-SanD: Knowledge Management, W. Venters, LSE, 2002

IT Strategy For Construction Companies, A Pragmatist's Vision, John D. Macomber, Leadership and Management in Engineering, Vol. 3, No. 2, pp. 94-99, 2003

Uncertainty and homebuilders' adoption of technological innovations, T. M. Toole, J.Const. Engrg. And Mmgt, 125(4), 1998

The AEC Dilemma-Exploring the Barriers To Change, Peter Beck, Leadership and Management in Engineering, p31-36, April, 2001

The followings are all research papers from Construction Research Congress: Winds of Change: Integration and Innovation In Construction, March 19-21, 2003, Honolulu, Hawaii

- Impact Of Information Concepts On Construction Performance / Dean Kashiwagi and Cliff Slater
- Providing Cost and Constructability Feedback to Designers / Sheryl Staub-French
- Component State Criteria Representation to Incorporate Construction Program Knowledge for Constructability Analysis / D. K. H. Chua and Yuanbin Song

- Agent-based Document Control for Large Projects / Michael Terk and Arun Kumar Srinivasan
- Critical Success/Failure Factors in Implementation of Web-Based Construction Project Management Systems / Pollaphat Nitithamyong and Mirosław Skibniewski
- Knowledge Management for Sustainable Construction: The C-SanD Project / Dr. M. M. A. Khalfan, Dr. N. M. Bouchlaghem, Prof. C. J. Anumba, and Dr. P. M. Carrillo
- Knowledge Management Strategies: Learning From Other Sectors / Patricia Carrillo, Herbert Robinson, and Francis Hartman
- The Effect of Construction Organization Management Practices on Project Success / Elizabeth Kraft and Paul S. Chinowsky
- Construction Methods Feasibility Reasoning in an Integrated Environment / Asad Udaipurwala and Alan D. Russell
- Integration of Construction Documents in IFC Project Models / Carlos H. Caldas and Lucio Soibelman
- A Framework For Integrated Data Management In Smart Infrastructure Systems / Tamer E. El-Diraby
- Future Directions for Model-Based Interoperability / Thomas Froese
- Web-based Electronic Data Interchange Model to Improve the Collaboration of Participants in Construction Projects / Hyun-Soo Lee, Sun-Ju An, Bo-Sik Son, Myung-Houn Jang, and Yoon-Ki, Choi
- The E-COGNOS Project: Current Status And Future Directions Of An Ontology-Enabled IT Solution Infrastructure Supporting Knowledge Management In Construction / Celson Lima, Tamer El Diraby, Bruno Fies, Alain Zarli, Elaine Ferneley
- An Architecture for Knowledge Management in the AEC Industry / John I. Messner, PhD
- Ontology Modeling of IDEF3 Process Description for AEC Applications Interoperability / G. Tesfagaber, N. M. Bouchlaghem, A. N. Baldwin, A. F. Cutting-Decelle, Malik M. A. Khalfan
- Implementation Of Enterprise Resource Planning (ERP) Systems In The Construction Industry / Syed M. Ahmed, Irtishad Ahmad, Salman Azhar, and Suneetha Mallikarjuna
- Information Technology and Cultural Change in the Construction Industry / Dr. Yvan J. Beliveau
- Tablet and Wearable Computers for Integrated Design and Construction / George Elvin, PhD, Assoc. AIA
- A Strategic Approach to Information Communication Technology Diffusion – An Australian Study / P. W. Goldsmith, D. H. T. Walker, A. Wilson, V. Peansupap
- Follow the Money: What Really Drives Technology Innovation in Construction / John D. Macomber
- Understanding Information Usage by Residential Construction Supervisors and

- Bridge/Structure Inspectors As a First Step in Adoption of Field Based IT / Thomas Mills and Ron Wakefield

- Information Technology Innovation: A View Of Large Contractors / T. Michael Toole, Member, ASCE

- Present And Future Of European Research On Information Technologies In Construction / Alain Zarli, Yacine Rezgui, and Abdul Samad (Sami) Kazi