CRITICAL SUCCESS FACTORS FOR CONSTRUCTION ICT PROJECTS – SOME EMPIRICAL EVIDENCE AND LESSONS FOR EMERGING ECONOMIES

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SUMMARY*: The application of information and communication technology (ICT) in the architecture, engineering and construction (AEC) sector has evolved over several years. Organisations continue to invest in ICT in their bid to harness technology and streamline business processes. However, construction organisations continue to experience perennial problems that militate against successful implementation of IT projects. This results from cultural, organisational and other operational constraints. This paper reports on research conducted in Hong Kong SAR China, over the period 2000-2004. The research methods include a combination of industry surveys, qualitative deductive analysis, and interactions on some case study projects (i.e. interviews, in-depth discussions on, and analysis of 'successful and failed' projects) with different levels of construction personnel in Hong Kong SAR. Analysis shows that there are distinct characteristics and features of projects that determine their success or failure, starting from even the conceptualisation and initiation stages, and that the projects have different points of failure. The paper identifies two trajectories of IT project success and failure in construction, and the critical success factors that could be useful for IT applications in emerging economies, drawing on the personal experiences of the authors in emerging economies in Nigeria and Sri Lanka. It discuses the findings from the HKSAR study, and give recommendations in the context of learning lessons from ICT initiatives in order to improve applications in emerging economies.*

KEYWORDS: *ICT project management, critical success factors (CSF), evidence-based research, organisational behaviour, human resource management, developing countries, complex adaptive system.*

1. INTRODUCTION & BACKGROUND TO STUDY

This paper discus IT projects in construction, and the success factors for IT-driven process innovation in construction organisations. A proper understanding of the theoretical underpinnings and the multi-dimensional critical success factors – CSFs (i.e. CSFs and barriers) to successful IT projects, would be of considerable practical value to emerging economies as construction organisations appraise their projects and take investment decisions. The paper reviews the efforts of construction organisations to introduce, implement, and adapt IT projects, using the metaphor of complex adaptive systems. Within this paradigm, IT projects are viewed as socio-technical systems in which there are intertwined complex factors (social, human, technological) that interact within the system environments, but all of which synergistically underpin the project success. It proposes a classification system that can serve to identify 'at risk' construction IT projects (which seem destined for failure from the outset). The classification, which examines the *epistemological* and *ontological* dimensions of IT-driven knowledge management and diffusion at various levels in construction organisations, can be extended to other IT project management domains in emerging economies and developing countries. The work is based on research conducted in HKSAR over the period 2000-2004, including analysis of relevant worldwide literature. The study indicates that organisations that hold on to neo-mechanistic models and theories of scientific human resource management (such as expounded by Fredric Taylor for the industrial revolution period) are more likely to experience higher failure rates in their IT projects in the present-day knowledge-based economy. However construction organisations that create an enabling and empowering environment for their workforce through appropriate management interventions are more likely to implement successful IT and knowledge management projects. The paper draws from the above study to provide a classification system that can facilitate identification of risks associated with construction IT projects, and formulation of mitigations, development strategies, and appropriate management control measures for project implementation. These constitute useful lessons for emerging economies in their IT implementations, adoption, diffusion and use in construction.

2. RESEARCH MOTIVATION & RELATED WORK

The HKSAR research study set out to investigate several related questions. The general problem addressed is: what are the critical success factors (CSFs), and barriers that impact the implementation, adoption, usage and diffusion of ICT in the construction industry? This raises several related research questions: (1) What are the key enablers for successful IT implementation and use? (2) Are there specific technical, commercial, organisational, and human resource factors that impinge on IT implementation? (3) What are the main underpinnings and what provides the impetus for IT investment? Is it driven top-down (e.g. by top-level management as part of corporate policy/strategy) or bottom-up (e.g. by operational requirements of the workforce)? (4) What are the stakeholders' perceptions of actual benefits, risks, and benchmarks, in industry practice? (5) What is the appropriate framework to address the multi-dimensional aspects of IT implementation in construction (i.e. people, process and technology components). Such a framework should enable identification of at-risk IT projects during the early stages of project evaluation, and facilitate formulation of appropriate risk mitigation measures. Thus the broad aim of the research was to investigate and identify answers to the above research questions and proffer potential solutions that are appropriate for ICT development and use in construction. However, the focus of this paper is on research questions 1, 2 and 5. Ugwu et al (2006) discuss further details on the research.

There is an abundance of documented literature (e.g. from past ASCE and CIB proceedings and other conferences on construction IT) that describes various research projects in construction, which focus on IT–driven construction process innovation. However, while the majority of the research focuses on developing improved product, process and computational models, there is a noticeable dearth of research that focuses on issues and factors that impinge on the uptake of IT systems in construction, including stakeholders' perceived benefits, costs and risks of IT systems in practice. An adequate understanding of perceived and expected benefits would facilitate an unambiguous understanding of user requirements and subsequent translation into system functional specifications during development. IT implementation in construction results in significant changes and potential improvements in design and management processes within the organisation. It is therefore necessary to investigate critical success factors as well as inhibiting factors.

Some research in mainstream computing and software development have investigated the socio-technical aspects of systems development and application in organisation (Barrow, 19990), Bingi et al (1999), Holland and Light (1999), Bourque et al (1999), Houdeshel and Watson (1990), Watson et al (1991), Watson and Frolic (1993). Other researches reported in literature have focussed on investigating the various basic and niche application areas of IT in construction. Such studies have been conducted in Singapore (Hua 2005), Norway (Samuelson 2002), Scandinavia (Howard et al 1998), New Zealand (Doherty 1997), UK (Egbu & Botterill 2001), (Ugwu et al 1999). The proliferation of research on IT barometers in construction on national and cross national basis indicates increasing interest to investigate socio-technical aspects of software development and use in the AEC sector.

3. METHODOLOGY – QUESTIONNAIRE DESIGN AND SURVEY

The research model was designed to investigate various related questions outlined in the preceding section. The research instruments include a combination of structured open-ended interviews, questionnaires and evidence-based research used for further validation.

Several research methods were adopted in the multistage research. The first stage conducted over the period 2002-2003, used a combination of pilot questionnaire survey, structured interviews with senior personnel of leading construction organisations in HKSAR, and deductive analysis techniques for interview protocol analysis (Ugwu et al 2003a). The second stage of the study conducted over the period 2003-2004, used a combination of questionnaire-based survey and case-study/evidence-based research techniques. The ensuing section discusses the second stage survey in detail, as it underpins the discussions in this paper.

Fig. 1 shows the research model used to investigate the various related questions. The research framework is broad and covered different dimensions of information and communications technology (ICT) in the architecture, engineering and construction (AEC) sector. These include; current applications of IT in construction, success and inhibiting factors, perceptions of IT application areas in solving construction problems, and organisational strategic directions in IT application.

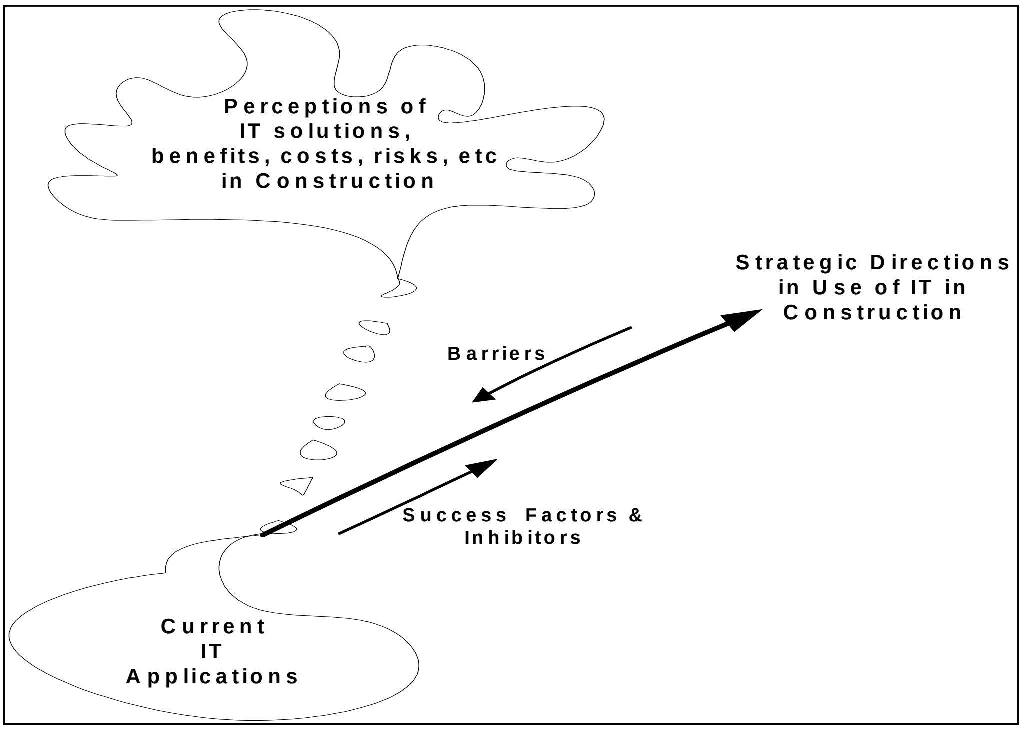

FIG.. 1: *Research Framework – ICT Applications, Success Factors, Barriers, Benefits & Risks*

This paper focuses on the critical success factors aspects of the study encapsulated in the framework. The research instruments include a combination of structured open-ended interviews, and questionnaires. The *evidence-based research* approach involved analysis of some completed case-study ICT projects, extracting relevant pre- and post-project evaluation data from the personnel (i.e. ICT experts) involved in the project implementation and use, and then coding the extracted data for further analysis and validation. This is then used for theory-building using the complexity theory (section 4).

3.1 Pilot Survey - Stage 1

The study used deductive analysis techniques to identify the key issues from the research framework. This involved; (i) transcribing the interview protocol data, (ii) collapsing some of the comments and statements to minimize repetitions, (iii) identifying words in the comments that relate to various factors and (iv) mapping/translating these into sets of key factors in combination with existing literature. However, caution was taken to avoid over-collapsing the statements and comments from the respondents since these were made in specific contexts. The identified critical success factors are summarized in Table 1. A simple ranking system was used to identify the priority areas based on the deductive analysis. Ugwu et al (2003a) gives details of supporting evidence from the interviews from which the key factors were extracted and synthesized. These comments are classified into 4 orthogonal variables at organisation levels. Three of these (i.e. leadership, communication, implementation team) are often discussed extensively in MIS research, but the fourth (i.e. externalities) was identified from this study as a very significant differentiator of the construction industry.

TABLE 1: Summary of Key Enablers for IT Implementation (Source: Adapted from Ugwu et al 2003a)

IT - Enablers	**Stakeholder**	**Total**	**Rank**		
	CLIENT	**CONSL**	**CONTR**		
Human resource considerations (People dimension)	2	2	3	7	1
Competence of in-house team	2	2	2	6	2
Standardization (Product & Process)	2		4	6	2
Company turnover	1	2	2	5	4
Evolutionary development	2	1	2	5	4
Appropriate software (off the shelf)	1	1	1	3	6
Clear communication with staff (Trust & openness)	2	1		3	6
Clear definition & understanding of user requirements	1	1	1	3	6
Cost of development		2	1	3	6
Development team knowledge and understanding of construction processes & business environment	1	1	1	3	6
Ease of use	1	1	1	3	6
Employee training needs & staff competence		2	1	3	6
Appropriate hardware technology		1	1	2	13
End-user involvement	1	1		2	13
Externalities (e.g. Government ordinances, Macro- and Micro-economic policies)		1	1	2	13
Return on investment		1	1	2	13
Standard platforms for integration & communication	1		1	2	13
Clear communication of IT objectives to management			1	1	18
Competence of partners & stakeholders in the supply chain			1	1	18
Outsourcing (use of consultants)	1			1	18
Top management support (leadership)			1	1	18
Change management at organisational level					
Interpersonal skills		1		1	18
General perception of IT as improving productivity					

3.2 Enlarged Construction Industry Survey – Stage 2

The methodology adopted in the second stage of the study is a questionnaire-based survey and evidence based-post project evaluation. The ensuing section discusses the processes in detail.

3.2.1 Questionnaire Survey

The constructs that define critical success factors (CSFs) were identified and abstracted from protocol transcripts of the interviews with construction organisations in stage 1 of the research, as summarised in the preceding section 3.1. Relevant literature including mainstream management information systems (MIS) research was also reviewed. These were then mapped as *key enablers and barriers* for validation in the next stages of the research. The second stage questionnaire survey validated constructs identified in stage 1. In the second stage of the study, an enlarged sample target group for the questionnaire survey was selected from the telephone directory "Yellow Pages", the member lists of The Association of Consulting Engineers of Hong Kong, The Hong Kong Institute of Architects and The Hong Kong Institute of Surveyors. The questionnaires were mailed, with a stamped addressed return envelope enclosed, for respondents' returns, comments, feedback and completion, to 345 organisations, including architects, consultants, contractors, QS and private and public clients. However, following an initial very low response, telephone calls were made to contact some organisations to seek their cooperation on the survey. At last, forty valid responses were received from the survey and the total consolidated response rate is 11.59% (approx. 12%). Table 2 shows details and distribution breakdown of questionnaires sent and the corresponding response rate from different disciplines. The responses were received in the period from October to December 2003.

TABLE 2: Distribution of Questionnaire & sample groups based on organisation types (Source: Analysis of Survey Data)

Group	No. of Questionnaires Sent	Percentage to All Questionnaires Sent (%)	No. of Responses	Percentage of Responses (%)
Planner	15	4.35	0	0.00
Architect / Architect & Project Manager	189	54.78	16	8.47
Consultant	52	15.07	8	15.38
Contractor	51	14.78	8	15.69
Private Client	18	5.22	0	0.00
Public Client	8	2.32	5	62.50
QS	12	3.48	1	8.33
Other (Unknown)	/	0.00	2	0.00
Total	345	100	40	11.59 (approx 12.0)

Legend:

Consultant: Include organisations of consulting engineers and consultant project managers; *Public Client*: Include public enterprises and government departments; *Multidiscipline*: Include organisations that are involved in more than one discipline of work, such as architects, project managers and IT; *Other*: Include unknown organisation types (i.e. those who did not indicate their organisation type in the completed questionnaire) and others, such as specialist instrumentation and site investigation contractor.

3.3 Analysis of Sample Characteristics

Fig. 2 provides a breakdown of the valid responses by respondent organisation type. Figs. 3 and 4 provide details about the sample distribution in terms of the number of people employed and the turnover of organisations. Of the 40 organisations, 50% employed less than 50 employees and 52.5% had a turnover less than HKD 50 million. Thus, over half of the sample comprised of small and medium organisations. Based on the organisation types, the whole sample is divided into 5 valid groups as described in Table 1. The data analysis in the later stage was then carried out based on this group division in order to provide a comparison of the survey results based on the different specialties of the responding organisations.

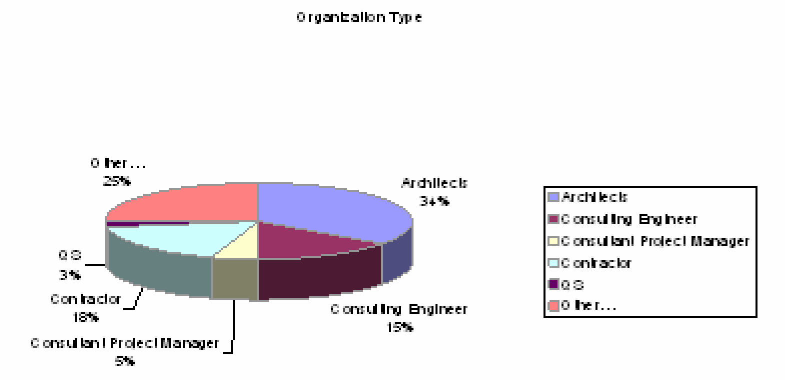

FIG. 2: Respondents by organisation type

On individual group bases, the sample of architects is from mostly small and medium firms, which have less than 50 employees and had turnovers of less then HKD 50 million. In the group of consultants, they ranged from very small scale with less than 10 employees to very large scale with about 250 employees. Their turnover ranged from less than HKD 10 million to about HKD 250 million. Most of the contractors are large scale with over 100 employees and turnover of over HKD 100 million.

For the data analysis, rankings obtained from the respondents about the key enablers and barriers (critical success factors) that they had experienced were used to develop an "IT benchmark index" (IT_{bi}). In calculating the IT_{bi}, all the numerical scores for the key enablers and barriers constructs were transformed to indices to assess their relative rankings (Love and Irani 2004). The IT_{bi} was calculated using the following formula:

$$IT_{bi} = \frac{\sum w}{AN}, (0 \leq IT_{bi} \leq 1) \tag{1}$$

where,

w = weighting given to each factor by the respondent, which in this ranged from 1 to 5, where 1 is "not at all" and 5 is "a very large extent".

A = the highest weighting, which is 5, and

N = the total number of respondents

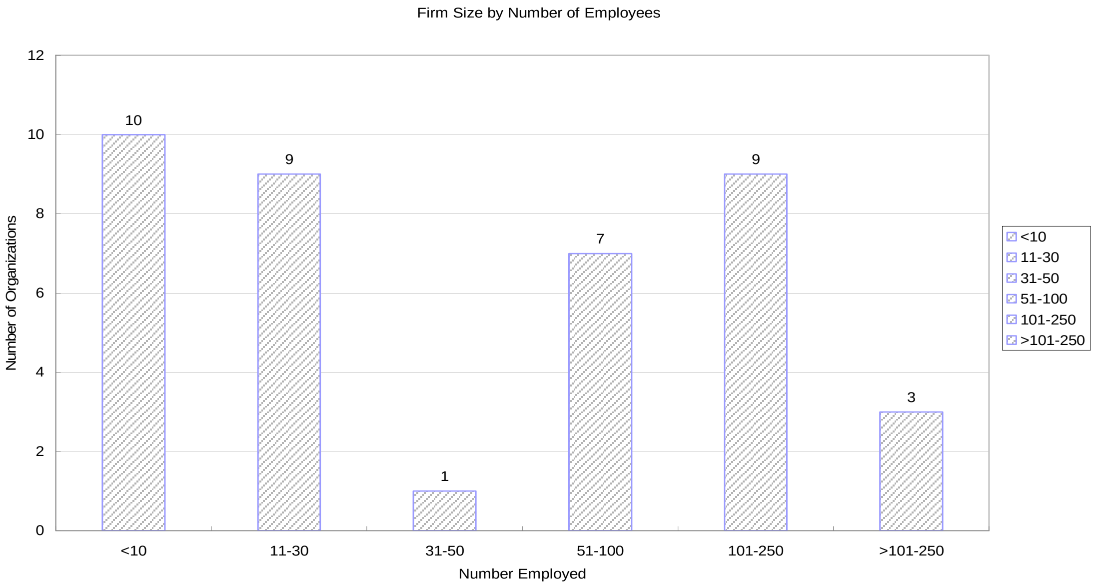

FIG. 3: Firm size by number of employees

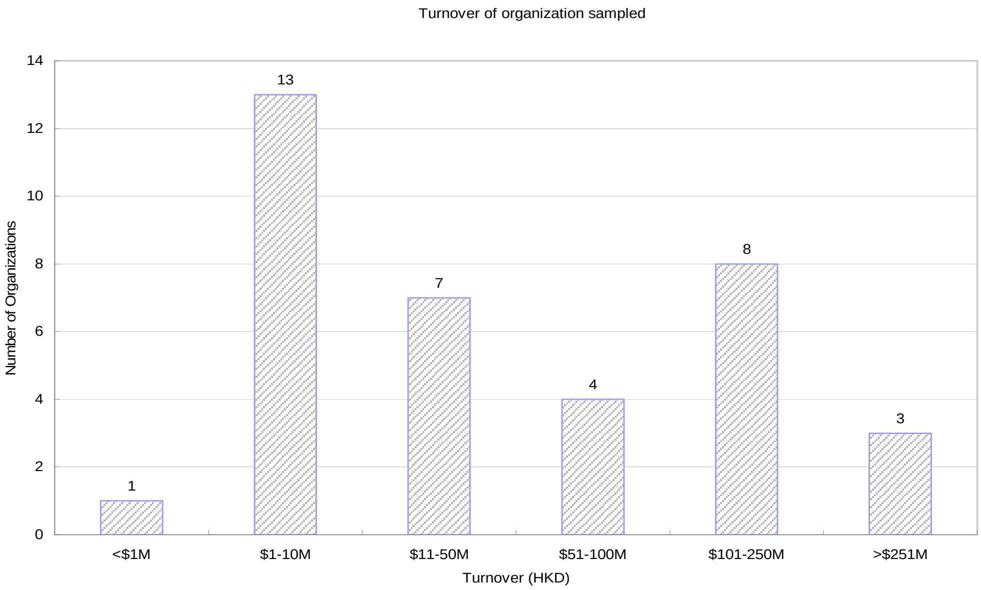

FIG. 4: Turnover of organisations sampled

3.4 Validation of Key Enablers and Barriers from Pilot Survey

Table 3 shows basic statistics (mean and standard deviation) of the key enablers and barriers (i.e. CSFs) identified in stage 1 based on the large sample in stage 2 of the study. Table 4 shows the rankings using the computed IT-benchmark indices. From Table 4, the top ten ranks in descending order are: Cost of development, Top management support (leadership), Appropriate hardware technology, Appropriate software (off the shelf), Ease of use, Development team knowledge and understanding of construction processes & business environment, Clear definition & understanding of user requirements, Clear communication of IT objectives to management, End-user involvement, and IT Competence of in-house team. Further analysis of the responses reveals that contractors ranked 'Ease of use' and 'change management at organisational level' as the first and second most significant success factors respectively, while the whole group of respondents collectively rank these as 5 and 16 respectively. Ease of use is a major issue that systems developers must address in any ICT project to minimise training requirements and the associated operational cost. Change management is a wider issue to address by the management to ensure that adequate measures are taken to cushion the impact on the work force, often engendered by changes in business processes that may result from introducing ICT systems.

TABLE 3: Characteristics of Key Enablers & Barriers (Source: Analysis of Survey Data)

Key Enablers & Barriers	**Mean**	**SD**	**n**
Appropriate hardware technology	1.846	0.904	39
Appropriate software (off the shelf)	1.821	0.942	39
Change management at organisational level	1.333	0.955	39
Clear communication of IT objectives to management	1.641	0.843	39
Clear communication with staff (Trust & openness)	1.487	0.970	39
Clear definition & understanding of user requirements	1.667	0.955	39
Company turnover	1.184	0.955	38
Competence of partners & stakeholders in the supply chain	1.184	0.801	38
Cost of development	1.923	0.957	39
Development team knowledge and understanding of construction processes & business environment	1.744	0.910	39
Ease of use	1.795	1.031	39
Employee training needs & staff competence	1.436	0.995	39
End-user involvement	1.564	0.968	39
Evolutionary development (i.e. step by step implementation)	1.333	0.838	39
Externalities (Government ordinances, Macro- and Micro-economic policies)	1.132	0.935	38
General perception of IT as improving productivity	1.436	0.788	39
Human resource considerations (People dimension)	1.436	0.821	39
Interpersonal skills	1.179	0.790	39
IT Competence of in-house team	1.538	0.822	39
Outsourcing (use of consultants)	1.308	0.832	39
Return on investment	1.308	1.104	39
Standard platforms for integration & communication	1.308	0.893	39
Standardization (Product & Process)	1.487	0.885	39
Top management support (leadership)	1.857	1.044	28

* Based on Likert Scale: (Don't Agree = 0, Slightly Agree = 1, Agree = 2, Strongly Agree = 3), the reference (Ugwu et al 2006), contains detailed analysis of the results.

TABLE 4: Benchmark Metrics of Key Enablers & Barriers IT Implementation (Source: Analysis of Survey Data)

Key Enablers & Barriers	All	
	IT ebi	Rank
Cost of development	0.481	1
Top management support (leadership)	0.464	2
Appropriate hardware technology	0.462	3
Appropriate software (off the shelf)	0.455	4
Ease of use	0.449	5
Development team knowledge and understanding of construction processes & business environment	0.436	6
Clear definition & understanding of user requirements	0.417	7
Clear communication of IT objectives to management	0.41	8
End-user involvement	0.391	9
IT Competence of in-house team	0.385	10
Clear communication with staff (Trust & openness)	0.372	11
Standardization (Product & Process)	0.372	11
General perception of IT as improving productivity	0.359	13
Human resource considerations (People dimension)	0.359	13
Employee training needs & staff competence	0.359	13
Change management at organisational level	0.333	16
Evolutionary development (i.e. step by step implementation)	0.333	16
Return on investment	0.327	18
Outsourcing (use of consultants)	0.327	18
Standard platforms for integration & communication	0.327	18
Company turnover	0.296	21
Competence of partners & stakeholders in the supply chain	0.296	21
Interpersonal skills	0.295	23
Externalities (Government ordinances, Macro- and Micro-economic policies)	0.283	24

Legend:
IT ebi – enablers and barriers index, * The reference (Ugwu et al 2006), contains detailed analysis of the results.

4. A COMPLEX ADAPTIVE SYSTEM VIEW OF CONSTRUCTION ICT PROJECTS

This section synthesises the findings of the research focusing on key enablers and barriers to successful ICT implementation and usage. It is a theory-building process that proposes a complex adaptive system (CAS) view of construction ICT projects. It is derived from complexity theory from point of view organisational science and systems paradigm (Parker and Stacey 1995). The CAS view takes account of the complex non-linear interactions between the various variables as they cumulatively impinge on the success of typical ICT projects. This CAS view underpins a framework for managing construction ICT projects. The framework could be used to identify at risk projects before taking go/no-go/do-minimum investment decisions. The CAS view, which is a superposition of organisational variables with knowledge management issues, is used to generate a classification (taxonomy) of ICT projects, which could be used to estimate the probability of success along the two trajectories of: (a) project management, and (b) ICT adoption and usage and diffusion to improve organisational business processes. In the context of this paper, 'at risk projects' are defined as those projects that appear doomed to fail from the outset. The failure could be along one or both project success metrics: IT implementation, adoption and use for business process improvement. As an illustration a project that is characterised by externalities such as high negative inter- and/or intra-organisational political dynamics may be successful from the point of view of project implementation (in terms of cost and time etc), but may fail in use (for instance if it requires sharing sensitive data and information across-organisational boundaries, at the system operational level).

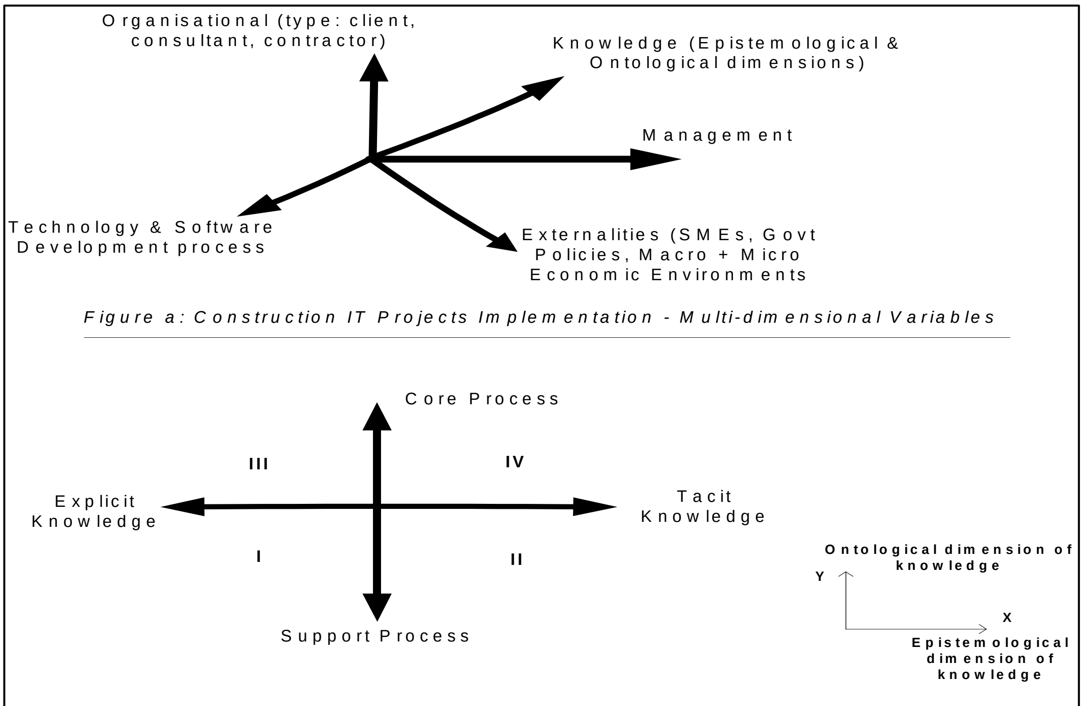

Figure a: Construction IT Projects Implementation - Multi-dimensional Variables

Figure b: Classification of Construction IT Projects - Knowledge Dimensions

FIG. 5: A Complex Adaptive System (CAS) View of Construction IT Projects
(Source of classification for Figs a & b: Analysis and synthesis of interview protocol data including several case study projects discussed by the interviewees, literature on knowledge management, and information systems management).

Figs a & b in Fig.5 above, result from a synthesis of interview protocol data in the first stage of the research with emphasis on micro-level issues/factors that impinge on implementation, adoption and diffusion of IT projects. The abstractions are derived based on the case study projects discussed in detail (and demonstrated to the researchers in some cases) by some of the organisations using their in-house IT systems. However, these projects cannot be discussed in detail in compliance with the understanding the researchers reached with participating organisations to maintain confidentiality. These commercial ICT systems differ in complexity and application areas. Analysis reveals interaction of different variables in a complex multi-dimensional space. This multi-dimensional space is captured using the superimposed diagrams in Fig. 5. They include organisational, externalities, technology and software, and knowledge dimensions. The classification in Fig. b shows the complex interaction between knowledge management issues and IT implementation and adoption. The proposed complex adaptive systems metaphor to understanding IT projects is pivotal to explaining the complex web of issues in the real world of information systems development and applications in construction organisations and other sectors (e.g. manufacturing, services and financial sectors).

Note: There is an element of fluidity in the classification and continuum of the quadrants and the ratings are qualitative and context/project-specific. Also there is no physical boundary in Fig. b. For instance, knowledge of an engineering solution that is initially a core tacit process can with appropriate enabling environment, be extracted and documented (even leading to voluntary knowledge conversation from tacit to explicit by the knowledge workers who have such knowledge fragments), so that it becomes an explicit type of knowledge but also remains an internalised core process at the intra-organisational level[1].
The ensuing section discusses these in detail.

[1] This assertion is based on real experience discussed by one of the organisations that participated in the interviews.

Organisational Dimensions (Stakeholders, Type & Structure): Stakeholders include: Client, Consultants, Contractors, Other suppliers. The organisational structure of the supply chain is important because a supply chain is as strong as its weakest link in terms of ability and skills to deploy and use IT systems for process innovation.

Management: The focus here is on human resource issues. The variable refers to leadership style, style, trust & openness, communication etc, corporate power and influence – the role of authority and institutional arrangements. The issues here include corporate power and motivational strategies to create an enabling environment for the workforce to be committed to the organisational objectives in implementing ICT systems.

Externalities: These extend beyond intra-organisational structures and include other participants in the construction supply chain such as small and medium enterprises (SMEs) that often have limited resources for investments and/or skill training in ICT, Govt policies (ordinances, laws, etc), macro and micro-economic environments that impinge on revenue streams,

Technology & Software Development Process: The underlying variables here include standardisation & interoperability, platforms, hardware/implementation cost, software implementation process (domain knowledge modelling, user-requirement capture, etc)

Knowledge Dimensions: These relate to knowledge types; Tacit & Explicit (epistemological dimension). It also includes knowledge creation, sharing, diffusion, and re-use (Ontological dimension) as they constitute the main underpinning for executing different construction business processes. It also includes support and core processes which are addressed by the ontological dimensions of knowledge. This dimension underscores the fact that knowledge workers cannot be used and disposed off at an organisation's will. Thus Taylor's mechanistic theories and models would collapse here if applied inappropriately. Industrial revolution work environments of the periods drove the formulation of such human resource management theories and practices, but these do not necessarily hold in the contemporary knowledge-based economy.

X-axis: (Right direction – indicates increasing difficulty with extraction, documentation, standardisation, distribution and re-use).

Y-axis: (Upwards direction: increasing complexity for knowledge creation, sharing and re-use). The features include: increasing difficulty for knowledge creation, storage and re-use, increasing value adding; increasing need for and complexity in business process re-engineering; increasing difficulty for standardisation; increasing internalisation at both individual worker and organisational corporate levels; and increasing cognitive/knowledge intensive processing.
The various project types in the quadrants are discussed below:

Quadrant I - Support Process & Explicit Knowledge (SPEK) Projects: Projects in this quadrant focus on support processes and routine services such as information search, storage, access and retrieval when needed by users. These are often support-tasks and processes that are characterised by distributed information integration and are coordination-oriented. Such projects are most suitable for process automation, and organisational outsourcing for development (e.g. as demonstrated in most web-based project systems, emails co-ordination applications etc). There is easy availability and access to knowledge content and sources. Such projects may be suitable entry points for application of state-of-the-art computing techniques such as the intelligent agent paradigm (Ugwu et al 2003b, 2006).

SPEK projects are characterised by decreasing need for business process re-engineering. Hence they are more likely to be widely adapted at organisational levels. Such projects are also more likely to be outsourced by construction organisations. Examples include Web-based project management/coordination systems. The emphasis here is often mostly on messaging and communication routing (e.g. in design and project management), and IT tools for content management.

Quadrant II – Support Process & Tacit Knowledge (SPTK) Projects: Projects in this quadrant need a greater degree of incentivisation and support for innovation on the part of the knowledge worker. Products here are more likely to be internalised by organisations but not necessarily shared at inter-organisational levels. Such internalisation improves their competitive advantage in the market place, and this is often a precursor for vertical and/or horizontal integration in business operations and service delivery.

Quadrant III – Core Process & Explicit Knowledge (CPEK) Projects: Examples of projects in this quadrant include typical Electronic Document Management Systems (EDMS) and Web-based/ Intranet applications. The knowledge sources include organisational design guidelines, and other procedures that are embedded within the organisation. Organisations are more likely to internalise this competitive advantage, and there is less room for outsourcing except for public clients who do not see any market threats. As an illustration, a government bureau completely outsourced its EDMS project to a Software firm and was willing to open up the entire operational structures for the consultant to understand the business processes the system would support. CPEK projects need very good staff motivation and neo-mechanistic human resource management model may be counterproductive in managing such projects from point of implementation and use. This is because knowledge workers and organisations hold strongly unto their knowledge stock, as this remains the most significant and niche bargaining power of both individual and organisations. Thus management needs to create an enabling environment ("Zone of indifference") that addresses the related issues in Maslow's hierarchy of needs. A case story illustrating the impact of this zone of indifference was demonstrated in an organisation whose staff identified a pattern of solving a frequent engineering problem and developed an 'intelligent solution'. The developed solution was subsequently standardised within the organisation and led to the development of an IT tool that was made available throughout the organisation. This demonstrates the interaction between organisational motivation and innovation in construction achieved by entrenching an enabling working environment.

Other examples of CPEK projects include EDMS & Knowledge Management Systems. The interviews reveal that generally, there is not much problem for public sector clients and Non-governmental organisations - NGOs (i.e. if such systems are deployed for intra-organisational use, except in situations where NGOs compete with each other for contracts). However, such inter-organisational collaboration may not hold for others in the supply chain due to market and commercial considerations. For example a construction organisation successfully uses an intranet EDMS for knowledge and document management. This organisation has operational guidelines, knowledge structures and expertise problem-solving skills that are easily and readily accessible by employees all over the world. In another case, an organisation did not want to expose their application product data models for web-based inter-organisational integration, but would rather receive specifications from clients in a structured format, so that they map these into their in-house application product models. Their decision was commercially-driven.

Quadrant IV – Core Process & Tacit Knowledge (CPTK) Projects: Projects in this quadrant are the most complex and are often times mostly research-driven. An organisation needs to have reached a very high level "zone of indifference" in the human resource dimension. Examples of areas that projects here are most suitable include highly cognitive processes and tasks, which include innovative design and project management solutions (e.g. designing for sustainability). Again the main thrust of the argument here is that Newtonian mechanistic models of human resource management have very little or no chance of success here. Thus the classification/taxonomy shows the complex interactions between motivational aspects of human resource management and knowledge management issues, in IT implementation and adoption. The proposed paradigm takes a holistic approach to understanding construction IT projects implementation, and is pivotal to addressing the complex issues engendered in the real world.

CPTK are mission critical projects. Projects here test the open systems metaphor (Ugwu et al 2003b, 2006) to the limit with high a stress level. Anecdotal evidence indicates that a project in this quadrant appears doomed to fail from the conceptualisation unless there is an exceptional positive enabling environment for implementation adoption, usage and knowledge diffusion.

5 EVIDENCE-BASED VALIDATIONS OF CRITICAL SUCCESS FACTORS – STAGE 3

5.1 Data Collection and Analysis

This section uses empirical data to verify the impact of the critical success factors (CSFs) and the validity of the CAS framework proposed in section 4. This would underpin further development of the CAS framework. This stage of the research was conducted in parallel from September 2003 – May 2004. The processes of data collection include:

1. identifying some completed ICT projects (where an ICT system was deployed for use) and collecting detailed information regarding features of these projects;
2. identifying the staff who were involved in the system development and subsequent use in organisational business processes and tasks;
3. using a questionnaire-based instrument in which the key participants in (ii), gave quantitative assessments of how far the critical success factors were present in the projects, on a scale of 1-10. The respondents also quantified the success of the ICT system from two trajectories – (a) project implementation as measured by completion on time, within budgets etc and (b) adaptation and usage of the implemented systems for business process improvements across the construction organisation.

The participants were also requested to include and/or state in their own words any critical success factors they deem important as impacting the success of ICT projects in construction, but which are not included in the study, based on their practical experiences in these case study ICT projects. Table 5 shows the summary of respondents indicating their roles/responsibilities in the projects. Minimal description is given in order to maintain the confidentiality of participants' details. Table 6 summarises the project description.

TABLE 5: Role / Responsibility of Respondents

Project ID	**Respondent ID**	**Respondent's Role / Responsibility**
A	A1	A very senior staff highly involved in project implementation and operation
B	B1	An engineer involved in project implementation and operation
C	B1	An engineer involved in project implementation and operation
D	D1	An engineer involved in project implementation and operation
E	E1	A very senior staff highly involved in consultation study of project
F	E1	A very senior staff highly involved in consultation study of project

Table 6 shows that projects A & C require data input from external sources – consultants and contractors. However, relying on the goodwill of stakeholders to provide data for system operations poses a significant risk to the ICT project success, in terms of using this to improve business processes. This problem/risk element stems from the high premium attached to data and information in construction marketing vis-à-vis market and business intelligence.

In addition to the above, some of the respondents provided comments and identified other factors that have impacted on the success of ICT projects. These are highlighted below:

1. **Industry Culture**: Cultural change is an important factor that affects the success of the system. One interviewee indicated that most of the end-users are already used to the traditional paper-based systems and find it difficult to change their ways of working.
2. **Turnover:** Company turnover and return on investment are not considered critical in government systems. However, this could have significant impacts in the private sector.
3. *Externalities*: Externalities such as government ordinances are not crucial factors for some systems like E-tendering. This is because E-tendering is only a change of medium for tendering.
4. **Legal Aspects**: Some of the main issues such as legalities will require much debates and discussion for a sound development of the supporting systems (e.g. legalising email-based transactions as contractually binding in dispute resolutions).
5. Sometimes the operating staff do not have the means to encourage the usage rate of the system.

TABLE 6: Brief description of different projects

Project ID	Project Features & Functionalities to meet End-User Requirements
A	• Information management system consisting of various project data/information such as project costs and project documents. • Provides immediate and up-to-date information to system users in case of dispute resolution. • Implementation involved different organisations or departments • System is used to collect data from contractors, consultants and clients who are required to input data into the system.
B	• A system enabling contractors and consultants to make electronic submission of project plans and drawings for approval by the clients department. • Allows fast and safe submission of project plans and drawings to the client's approving department. • Implementation involved the purchase and customisation of required software and associated hardware.
C	• An information management system, which collects data and information on project developments. • Designed to monitor the whole project delivery process from construction to occupation according to the approvals given by the client's designated department. • It mainly allows internal usage of information between different distributed (but co-located) functional departments in the organisation. • Consultants and contractors input data and information into the system.
D	• Used to coordinate and monitor works to be scheduled on public roads and public-owned lands (i.e. mainly for data/information search and retrieval). • It is designed to minimize inconvenience brought to the public and avoid/minimize chaos, due to project construction. • Contractors and sub-contractors are required (obliged) to make applications through the system if they intend to carry out excavation works on captioned areas.
E	• A proposed electronic communication platform, which is expected to facilitate collaboration and communication among various project teams such as clients, contractors and consultants, whether they are distributed or co-located. • Designed to increase the speed of communication and improve the documentation processes. • Not yet implemented at the time of study, but an in-depth feasibility study had been completed
F	• A proposed system expected to facilitate electronic submission of tenders to the client • Would allow fast and safe submission of tenders resulting in significant savings from printing charges and paper costs, and other transactional costs. • Not yet implemented at the time of study, but an in-depth feasibility study had been completed.

Table 7 shows the aggregate assessments of these case-study evaluation projects by the participants. The scoring of the projects was carried out by participants involved in the projects as described in Table 5. The process is similar to balanced score card systems. In this research, the separate scoring sheets that capture the CSF constructs, project and assessor details, were given to participants. They assigned quantitative numerical values (in percentage terms) that measure (i) the impact of the identified CSFs, and (ii) the project performance. The scores are based on the respondents' respective judgements.

TABLE 7: Corresponding Level of Success (Implementation and Usage)

Project	**Numerical Measure Critical Success Factor (%)**																						**Level of Success (%)**	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**S1**	**S2**
A	80	80	100	100	60	60	80	40	80	80	100	100	80	60	40	100	100	80	80	100	20	20	60	50
B	60	80	60	20	60	80	80	80	60	80	80	80	100	60	100	80	20	60	80	80	80	80	80	60
C	80	80	100	20	60	100	100	60	80	80	80	60	60	80	100	80	20	80	80	100	100	80	80	80
D	100	80	80	N/A	80	100	100	80	80	80	60	60	60	80	100	60	60	80	60	60	60	60	80	100
E*	80	100	100	N/A	60	80	100	100	100	40	80	40	100	60	80	100	N/A	100	80	100	80	80	ni	40*
F*	80	60	100	N/A	60	80	100	100	100	40	80	40	N/A	60	80	60	N/A	100	80	100	80	80	ni	70*

Legends: S1 = Implementation, S2 = Usage, ni = Project not implemented at time of survey
* Values estimated by respondent based on completed detailed feasibility studies for the projects, N/A = judged by respondent as Not applicable in the project.
Criteria: In order to interpret and discuss the data, a 70% subjective rule is applied uniformly to all the projects. This rule interpretation is as follows:
CSF: A given CSF is deemed to be significantly present if it is rated >= 70%.
Pass score: A project is deemed to have been successful if the score (S1 or S2) is >= 70%. Lower figures indicate lower levels of satisfaction.

Notes on CSF Coding *(symbolic codes are shown in bracket)*: (1) Human resource considerations (People dimension), (2) Standardization (Product & Process), (3) IT competence of in-house team, (4) Company turnover, (5) Evolutionary development, (6) Clear communication with staff (Trust & openness), (7) Clear definition & understanding of user requirements, (8) Low cost of development (i.e. low cost is desired), (9) Development team knowledge and understanding of construction processes & business environment, (10) Employee training needs & staff competence, (11) Ease of use, (12) Appropriate software (off the shelf), (13) Externalities (Government ordinances, Macro and Micro-economic policies), (14) Appropriate hardware technology, (15) End-user involvement, (16) Standard platforms for integration & communication, (17) Return on investment, (18) Top management support (leadership) , (19) Clear communication of IT objectives to management, (20) Security of data storage and transfer, (21) Flexibility of the system to suit actual situation, (22) Existence of reputable and reliable service providers.
CSF codes (1) to (19) correspond to the validated key enablers and barriers (Table 4), which were identified, from the pilot study (Table 1)
CSF codes (20) – (22) were identified in the follow up studies in stage 2.

Fig. 6 shows a graphical representation of the results. The results and observations are discussed in the ensuing section.

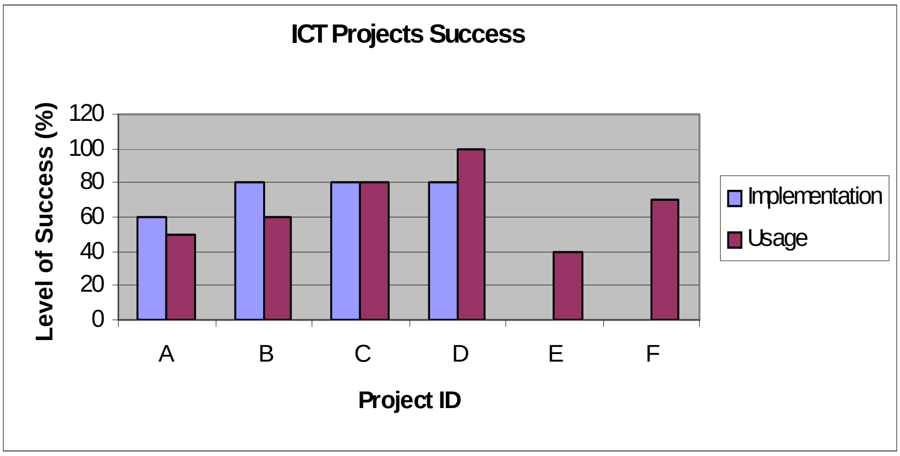

FIG. 6: *Level of Project Success (Source: Analysis of Case Study Projects Research Data)*

From Fig.6 the following observations are made using the 70% rule (as indicated below Table 7):

1. All projects passed except project A that can be considered to have failed in terms of implementation and use, and project B that fail in terms of usage.
2. Projects A, B & D show some interesting features in terms of levels of success
3. Project D appears to be "100 % utilized" by the end-users, which is exceptional.
4. Project E clearly shows sign of 'stress' and potential failure if implemented.

Note: Projects E & F were not yet implemented at the time of study.
Projects A, B, and D are studied in more in-depth for analysis of the observations. These observations are explained using the complex adaptive systems paradigm (i.e. evolutionary analysis). This paradigm is described in the ensuing section.

5.2 An Evolutionary Model of the ICT Projects

This section analyses the results shown in Table 7, by transforming the data into a 'genetic coding'. This is then used to develop a genetic model of the ICT project systems/environment from the perspectives of project management. The impacts on project success are non-linear although these are cumulative. These complexity and chaotic dimensions (Parker and Stacey 1994) are subsumed in the CAS model described in section 4 (Fig. 5). For consistency, the 70% subjective rule is also applied in developing the evolutionary model. In this context, linguistic terms are used to express the state of the CSFs: a CSF that is rated 70% and above is classified as 'a healthy gene', otherwise it is classified as 'a defective gene'. Binary codes are used for the actual genetic coding. This is simple and yet expressive enough to capture the necessary details. A healthy gene is represented with 1, but 0 if unhealthy. Also in developing the evolutionary model, the fitness of any gene pool (chromosome structure) is measured using the real numerical values F1 & F2 assigned by the respondents (Table 8), with a maximum value of 1 indicating 100% fitness. This abstraction is expressive enough to capture the complexity and chaotic characteristics exhibited by the ICT projects. In management parlance, a defective gene could be 'repaired or improved' by injecting appropriate positive interventionist measures, which should result in improved fitness of a given chromosome structure. Table 8 shows the gene pool for all the CSFs. However the analysis focuses on the top 16 ranks from the field study (Table 4). The CSFs with codes 20-22 in notes on symbolic codings in Table 7 are also included. The fitness of a given chromosome structure is measured using the level of success. This is represented as F1 and F2 in Table 8. This is again consistent with the 70% rule (as stated in item (ii) below Table 8.

TABLE 8: (CSFs at the Top 16 Ranks)

	1	**2**	**3**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**15**	**18**	**19**	**20**	**21**	**22**	**F1**	**F2**
A	1	1	1	0	0	1	0	1	1	1	1	0	0	1	1	1	0	0	0.6	0.5
B	0	1	0	0	1	1	1	0	1	1	1	0	1	0	1	1	1	1	0.8	0.6
C	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1	1	1	1	0.8	0.8
D	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0	0	0	0.8	1.0

Legend: (i) F1 = Fitness value for implementation, F2 = Fitness value for usage, (ii) For each critical success factor: >= 70 (Chromosome structure: gene value = 1, and 0 otherwise)

5.3 Discussion of Observations

CSF codes 20, 21, 22 are all considered absent in D from Table 8. However, the IT project is widely used (F2 = 1.0). This observation may be explained because it is not used for mission-critical support process. In order to begin to understand the various observed scenarios, we use complexity theory to explain the observations. The CAS framework (Fig. 5) captures the observed complexity of socio-technical systems, and is critical to understanding the observations. The main lesson is to view ICT project environments as socio-technical systems with complex critical success factors (CSFs) that interact in the project space, and incorporate this in the project evaluation process. Such a holistic understanding is essential for decision analysis, and investment appraisal decision-making in ICT projects.

Project A: This is used for supporting core processes, and requires input of project data from external sources (consultants and contractors). Thus the success in usage relies very much on the goodwill of these external sources. These organisations place much premium on construction data because of the valued addition in areas such as business intelligence analysis. It falls within the intersection between Explicit/Tacit Knowledge and quadrant I & IV in Fig. 5. It is noted that project A was eventually phased out and replaced with other systems.

Project B: This is used for core process support (designs and tender submissions). The business processes and tasks require explicit/tacit knowledge from construction organisations. However, unguarded exposure could dilute their competitive advantages given the high premium attached to construction data in business/market intelligence. This project falls at an intersection between Quadrants III & IV, and demonstrates the fluidity in the CAS framework/classification.

Project D: This is used for support processes, and noted to be different from project A (essentially data/information search and retrieval by end users). These business processes and tasks require explicit knowledge from the end users. In addition users are obliged to use this for information search, demonstrating the impact of organisational power and influence in IT diffusion and adoption for such non-core processes. This project falls within Quadrant I in Fig. 5. It is noteworthy that despite the 'defective state' of CSFs such as 'security of data storage' and 'system flexibility', the ICT system is still assessed as very widely used (100% usage rate). This indicates that end users may not attach too much importance to security related issues if a system is deployed to solve non-mission critical support process.

Project E: This project was proposed to support core business processes (electronic submission of tender proposals) some of which are mission critical. The business process tasks also require considerable tacit knowledge at organisational levels. The project clearly shows signs of great stress, and projected usage was just about 40% (Fig. 6). The project was later discontinued and it did not progress beyond the feasibility stage. It falls within quadrant IV in the CAS framework.

6. CONCLUSIONS AND RECOMMENDATIONS

This paper has discussed a wide range of enablers and barriers for ICT applications in the architecture, engineering, and construction sector. Analyses of recent applications provide basic experiential foundations and theoretical underpinnings to understand challenges that face ICT development and diffusion in emerging economies.

Like most other sectors, successful implementation, uptake and diffusion of ICT systems is predicated on a set of critical factors. Some of these factors may depend on specific organisation attributes (e.g. size). This study identified some fundamental critical success factors that would act as enablers for successful implementation of

ICT projects in construction. The top CSFs identified are (Ugwu et al 2003a); (i) cost of development, (ii) top management support, (iii) availability of appropriate hardware and software (e.g. bespoke off-the-shelf solutions); (iv) ease of use of IT systems; (v) development team knowledge and understanding of construction business processes; (vi) clear definition and understanding of end user requirements (i.e. need for end-user driven IT solutions and applications development); (vii) clear communication of IT objectives to management; (viii) standardisation issues (to enhance interoperability of dispersed systems and platforms), and (ix) change management at organisational level (especially for large organisations)

The other barriers to the application of ICT in the construction industry can be discussed under the following headings: security, safety, user acceptance, level of investment in IT infrastructure, and the development of distributed computing architectures and frameworks that are suitable for particular construction problems (Ugwu et al 2005b, 2006).

Security: Based on assessments of the current state of computing technology, there are a number of security concerns in deploying both basic and advanced state-of-the-art ICT systems, to automate construction processes. Some of the security concerns in the IT sector, which also apply to the construction industry, include: email spam, spyware, phishing etc. The second security consideration relates to organisational information safety since an unauthorised software agent can modify or delete data from a system leading to very significant impacts on organisation's business processes, growth and sustainability. This may be considered even more critical in emerging economies where nascent organisations are even more vulnerable, given the lack of external support e.g. a reliable legal regime.

User Acceptance: The construction industry is still generally slow in its uptake of new technologies. This is partly due to the perceived failure of AI to deliver on its previous promise in the 1980s, which has contributed to users' reluctance in accepting new AI technologies. This is principally due to the overselling of AI systems (in the early years of knowledge-based systems and expert systems), with regard to their capabilities to mimic human intelligence in solving complex industrial problems. This experience at industry level has resulted in most AI research projects being confined to academic research laboratories. Construction ICT researchers need to guard against such overselling and ensure that the specific concerns and needs of industry are addressed in developing ICT systems for process innovation. There is need for end-user driven system development to ensure that user requirements are correctly captured. An evolutionary approach to technology uptake could be beneficial (Ugwu 2004). Again this issue is more significant and even takes on another dimension in emerging economies, where experience has been necessarily limited. User needs may need to be clarified after they are presented with various options, possibly with unbiased guidelines to help them towards realistic choices. The authors' experience in Nigeria and Sri Lanka indicate that it is feasible, and given the worldwide access to the internet, dissemination of such details of various options becomes even easier.

There is also another important social dimension to the user acceptance of ICT systems at the organisational (job function) level. This relates to the potential threat to job security that is often associated with the introduction of a new technology for process innovation. This could have negative impacts with respect to adopting and diffusing the technology to enhance productivity improvement. A solution would involve appropriate management intervention that is underpinned by targeted human resource management policies (Ugwu et al 2005a).

This paper has discussed the various critical success factors for ICT project implementation, use and knowledge diffusion at organisation operational levels. It also discusses a classification of construction ICT projects using the complex adaptive systems paradigm. This classification provides some bases for better understanding of socio-technical dynamics and interaction between the soft and hard system variables on ICT project environments. It used some case study project evaluations to elicit and highlight useful lessons on the impact of these CSFs. These are useful lessons for ICT implementation in the emerging economies, as well as in the architecture, engineering and construction (AEC) sectors in general in other developed countries. The findings indicate that there are clearly some roles for construction ICT research to contribute in addressing these enablers and barriers in ICT implementations. It is expected that Research and Development (R&D) will continue to drive progress in several aspects. Example of areas that R&D should address in the short and medium terms are: education (teaching and learning), interoperability and systems integration, user requirements capture, application of complexity and chaos theories as an underpinning framework to investigate the socio-technical dimension of ICT implementation, adoption and diffusion in construction organisations (as described in section 4 herein), and standardisation (e.g. using eXtensible Markup Language (XML) solutions.

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