DEVELOPMENT OF A TRIANGULAR TPC MODEL TO SUPPORT ADOPTION OF CONSTRUCTION INTEGRATED SYSTEM

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In recent years, considerable research and industrial efforts have been devoted to developing information technologies within the AEC industry. However it is generally believed that low level of value from IT investments has been achieved in AEC sector so far. Most AEC business managers still prefer traditional processes and methods and seem reluctant to embrace new IT based ways of working. One possible reason for this obvious gap between expectation and result is that too many previous research projects and industrial practise based IT initiatives adopted a technology-driven approach, without enough effort being given to understanding human behaviour, organizational culture, training and other barriers to adopt the new systems. IT is an enabler, not the solution. Many issues that affect the adoption and effective use of those technologies still need investigation. At present, there is a dearth of research focus on how to deal with the relationships between the technologies, process and culture. And it is noted that relatively little research effort addresses the problem of getting new technologies and process, product standard generally accepted. Moreover, it would seem from experience drawn from other industries, that in order to utilize advanced technologies, and optimised processed, to add greater value, an integrated adopting system should be developed. Based on a preliminary literature search and industrial collaboration in the areas of technology, process and culture, an 'ideal' triangle TPC model is suggested. It can be used to describe the inter-relationship and interaction among the three factors, and then form the adoption framework of new technology, process, knowledge and culture. This research presents a prototype of an integrated adopting system, which includes the optimised product and process model, an integrated technical framework, and organizational culture adaptation. It provides the comprehensive conceptual model for adoption of technology. The AEC companies can benefit from this integrated adopting system through more effective technology transfer, process improvement and information management. It also offers a traditionally fragmented industry with a strategy for better integration.

Keywords: culture, integrated adopting system, process, technology, TPC paradigm.

INTRODUCTION

Construction is a collaborative activity involving a multi-disciplinary team that includes for example: a client, an architect, engineers, numerous consultants, contractors and subcontractors. Each member of this team is responsible for certain aspects of the project. Different professions use their own unique processes to undertake their tasks, but often have to rely on information supplied by the others. At present, the communication problem between the team members is often a cause for

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project delay, expensive reworking and building defects. Improving the communication link is widely believed as crucial to further efficiency gain in construction (Latham 1995).

In recent years, there has been a rapid expansion of IT applications available to all construction professionals, but unfortunately, every categorized applications look like an ‘island of automation’, missing the all important ability to integrate with other applications. As a result, the same building information needs to be entered many times and stored at different places (Sun and Aouad 1999). Practically, the AEC industries demand better use of information resources: to improve work efficiency and collaboration through improved access to information. The potential for improvement within the industry has largely been linked to its ability to better coordinate work, to more efficiently communicate project information, and to more effectively use information resources to support asset management decision-making (Halfawy and Froese 2001). Flanagan (2001) claims big breakthrough will come when all communication technologies become integrated.

The concept of Integrated Engineering has become a key technological goal for major construction companies. It will bring many benefits to the AEC industry such as improved productivity from component-based design, lower cost, shorter lead times and clearer liabilities. The integration of the AEC sector is mainly based on the information exchange, knowledge reuse, and the integration of product and process. Unquestionably, if the AEC industry is to gain the benefits from the current information technology revolution, there will need to be a way to reliably exchange data among applications and possibly building equipment.

At present, the technologies of Integrated Project Database (IPDB), Virtual Reality (VR), Knowledge management, product modelling, process modelling are being developed in many institutions and firms with intent to integrated the fragmental AEC industry, but there are little effort to integrate those IT tools and issues behind technology, such as culture, process together. This research presents a prototype of an integrated adopting system, which includes the optimised product and process model, an integrated technical framework, and organizational culture adaptation. It provides the comprehensive conceptual model for adoption of technology.

This paper will first conduct the structural analysis of integrated system with technical perspective, evaluate the present development of integration, and outline the hierarchy and key components of the construction integrated system. Next, prior views of cultural and process issues are summarized. The following section introduces the paradigm of this research, a triangular technology-process-culture model. Then the conceptual prototype and mechanism of the model are established and examined. The paper ends with a discussion of the main benefits from this TPC model implication.

STRUCTURAL ANALYSIS OF THE INTEGRATED SYSTEM

Through categorizing the integration research, the profile of present investigations in this field is drawn out. Sun and Aouad (1999) divided on-going integration efforts into Electronic document management systems, Inter-operating autonomous systems, and fully integrated concurrent systems etc three levels according to the breath and depth of process and data integration. Generally, the first and second category cannot be considered as a viable, universal approach to integration, although many efforts have been devoted to concerned research. Actually, the third category depicts the direction of future development of integration. This kind of categorising presents a strategic view of on-going integration efforts, and addresses several main features of fully integrated concurrent system, such as knowledge of data as well as process, abilities to control the sequence of applications and so on. But it fails to reflect the impaction of human beings in the integration process, and integrate different visions of professionals. The fully integrated systems should be 'human' friendly, and address the issue of how humans intervene into a process and adapt to a new technology. Moreover, different perspectives from the participants should be communicated and exchanged harmoniously in this system.

Sturges and Bates (2001) describe the integrated system as a system where the essential operation data is entered once, and each department or function within company works from the same data. Although it is not a precise definition, it addresses that the core mechanism in integrated system is the mechanism of information Exchange. A well-structured system of handling and exchanging information is a prerequisite of a successful integrated system. The aecXML research group identified four main approaches to information exchange which have so far been tried in practice, especially in R&D of applications interoperability (aecXML Working Group 1999)

These include:

- Traditional way. Says Paper, phone, E-mail, faxes.
- DFT (Document file transfer). Any two software programs that need to exchange data agree on a file format for a given document type, and each reads and writes data in that format.
- APIs (Application Programming Interfaces). Publishing programming interfaces is an attempt to circumvent the inherent limitations of document file transfer.
- Fully shared databases. It is to rewrite the applications so that they all store information in a common, predefined database.

Those approaches can present the different mechanism of information exchange. However, result and feedback form industry and academia have consistently shown that approaches listed above can partially to assist the information exchange but they are not the integrated solutions.

At present, modelling the product data has become the popular means to assist information exchange. It is the core communicated component of the integrated system. aecXML and IFC are the two main initiatives to develop the product standard for the AEC industry. However, until recently the construction industry does not have the structure or foci to achieve the standardisation of data and protocols that would deliver efficiencies, lessen defects and encourage investment.

Process knowledge is also an essential foundation for innovation in construction, including adopting new tools and systems for use in future facilities and developing new construction processes. The scope of the processes covers all kind of operations from project planning, required decision-making, communication and sharing of project objectives towards common working standard for construction site operations and facility management. Increased understanding and application of construction process knowledge will provide an essential distinctive competence for the integrated and innovative firms (Tatum 1999). Process also influences the efficiency of knowledge capturing, transferring and how effectively it is used.

Besides the mechanism of information exchange, product standard and integrated process, the approaches to the integrated system also plays a crucial role, which represents the core techniques to realize fully integration. Eastman *et al.* (1997) contended that the essence of integrated construction is the ability for different professionals to share project information by either accessing a central data repository or by exchanging data electronically. Although it is a consensus that an integrated construction project database (IPDB) is the core technology for an integrated system, there is far less agreement on what form it should take (Aouad, Child *et al.* 1997).

Amor and Faraj (2001) summarised the approaches that have been proposed or adopted so far in development of the integrated project model:

- Project Models as Reference Model
- Centralised Project Database
- Distributed Project Database
- Neutral Formal Project Database
- Proprietary Approach

Every kind of approach has its own advantages as well as disadvantage. There are many efforts devoted into developing all kinds of integrated database respectively, but evolutionary path from those current systems to more data integrated approach is not clearly defined or understood. Some suggest using the distributed database and others try to adopt the centralised approach. According to comment from CICA on current industry initiatives (CICA 2000), they argued that it is impossible to include most comprehensive features together in one project database. The centralized project database is still the most favourite approach in many prototype and practical efforts.

Actually, there are many factors deciding which form of integrated system should be adopted in a specific firm. Those factors include tacit mechanism of information exchange, organisational structure, culture, mainly using design tools and the basic business process of a firm.

With the assistant of above centralised or distributed project database, participants of construction project can access all relevant project data in a timely manner without any compromise. This is a desperately needed solution, but it is not a sufficient solution. Even these kinds of technologies got a breakthrough, the problem of how human, process and technologies interact within new technical environment still remains on the fly. For example, electronic documents still require users to relate project information for decision-making. On the other hand, the low level of trust between project participants in current experience prevented the use of inter-organizational IT network.

The culture and process are therefore also indispensable factors to build an integrated system. Many firms in the AEC sector have considered the utilization of IT as a key target of development. But only in a very small number of leading companies, information technology is truly part of the core competencies. Antilakka and Kahkonen (2001) suggested that construction companies have not been considered as very opportunistic or pro-active organizations in the terms of taking advantage of new technologies or results from research and development. The dependability of technology and cost of IT are not the main obstacle for firms, however, the uncertain of benefit from process and culture changes holdbacks the enthusiasms of innovation. Those issues behind technologies need to be investigated further.

At present, AEC industry around world has been facing an unprecedented level of competition. To stay competitive in today's market, the AEC industry must develop and deploy IT solutions to perform tasks in a more effective and productive way. More importantly, human resource should be lift up to higher level. The AEC industry firms must develop and rely on people's skills and pass the information down supply chains in standardized forms, which support integration and are most appropriate to the needs of participants. Moreover, integrating the creation of knowledge and its exploitation as intellectual property of company has been considered as the key drive for sustainable development of a firm.

The performance of the construction industry in terms of productivity, quality and product functionality has been low in comparison to other industries, and a low rate of innovation has been provided as the major explanation to this situation (Gann 2000). In the survey conducted by Sturges and Bates (2001), they found the implementation of computer aided project management software and methods were in most case only partial, while the complete software package has never being used. Nam and Tatum(Nam and Tatum 1988) argued that firms which increase the degree of integration between design and construction can develop technology and gain competitive advantages based on it. In this research, inefficient usage of IT applications and systems are claimed to be due to a lack of integration in technology, process and culture of most companies. Adoption in this research could be defined as efficiently implementing, and deploying the IT technologies, continued use of innovations, and finally forming the integrated organisational knowledge base.

RESEARCH PARADIGM AND METHODOLOGY

Broyd (1999) claims that the industrial adoption of high technologies in construction sector can be described as a technology-process-culture (TPC) triangle. This research will develop this notion into a research paradigm. It is illustrated by the figure 1.

In this work, organisational culture acts as the foundation to support an integrated adopting system. Based on organisational culture, technology and business processes are coupled and underpin each other. Within the reiteration process of handling information and data in projects, companying with application of new technologies and reengineering of new processes, an organisational ambience of information sharing, knowledge reuse can be achieved as a result of the reasoned utilization of this triangle paradigm.

The features of this triangular TPC paradigm can be explained by the basic theories of triangle: The triangle is the most stable plane figure. Technology, Process and Culture in the TPC paradigm are most strongly connected and support one another. Three sides of the triangle can form the steady working platform of a company. Any change of side of triangle will result the change of other two sides sequentially. For example, if the applied technology in a firm changed, the culture and business process also need be adjusted to this kind of transformation.

On the condition that the sum of length of three sides is fixed, the area of an equilateral triangle is the maximum value. The area of the triangle could be depicted as the core competence of a firm. All of three factors should interact harmonically in order to realize the maximum benefit of the specific company.

This research presents a prototype of an integrated adopting system, which includes both a prototype and a suite of tools.

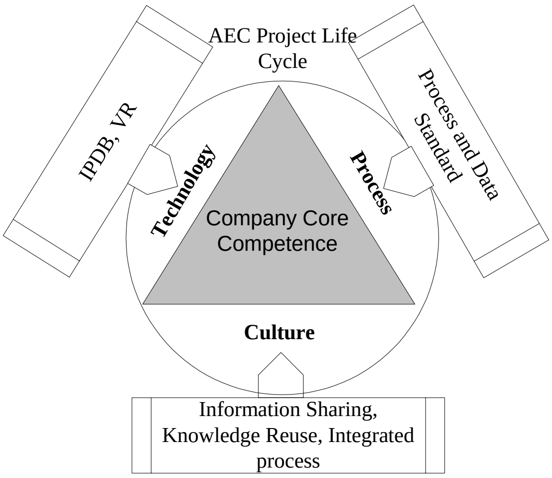

Figure 1 A Research Prototype: TPC Paradigm

Another paradigm applied in this research is that the AEC firms must transfer knowledge from other industries and depend on the existed tools to redevelop bespoke systems, which are suitable for the organizational culture. They do not have time or profit margins to rebuild core competencies independently.

Because the model introduced here is based on the process, technology and cultural issues, the approaches of hard system and soft system are both needed. The basic methods deployed in present stage are literature review, and data flow diagrams. The published literature related to technology, process, culture, integrated system and innovation was structurally reviewed. The Data Flow Diagrams is suitable technique to model the construction system as it consists of process linked by interface. Mapping the information flows between projects participants would help to gain greater understanding of the construction process. Next stage, a case study will be employed on DesignBase Project at WS Atkins. The construction integrated systems and software package will be examined though the software package analysis and interview with system designers. Software packages for construction individually provide a structured approach to their input requirements and output deliverables. By analysing the features of those inputs and outputs it was expected that process and product data suitable for exchange could be identified. On the other hand, in order to investigate cultural issues and its interfaces with technology and process, social network analysis is introduced to monitor the interaction between them and analyse the rate of adoption.

The main procedures of the research are: creating the framework of TPC model; analysing the generic process employed in a specific company; establishing integrated central project repositories; implementing data sharing and exchange through the use of model-based standard data format between system components; adopting existing model to AEC projects to support the implementation of construction integrated system; monitoring the rate and process of the adoption.

PROTOTYPE AND MECHANISM

Firstly, based on structural analysis of the integrated system, the three factors are investigated individually, and then with introducing the iteration project process life cycle, they are integrated together to build up the organisational knowledge base and core competence.

Product Standard
In this research, the aecXML and ifcXML will be merged to develop the framework of product data. Once the process of forwarding research, the consistency of those standard should be affirmed.

Process Optimisation
In construction industry, the diversity and complexity of knowledge involved in previous projects require many years of experience to acquire and effectively apply this experience. Information technology can help but we need much better understanding of the content of knowledge bases for design and construction processes. This research will streamline different process of a temporary network of companies implementing construction projects with the help of available tools (such as iPronet developed by WS Atkins).

Technical Model
Advanced Information Technology today gives us the opportunity to implement sophisticated distributed systems for collaborative design. This research will focus on technologies for assisting design and develop an open model that enable the collaboration/sharing between disciplines at any level of IT capability. Based on the technique of data flow diagrams, the model illustrated in Figure 2 is introduced. It presents the technical model employing in the TPC integrated system.

The case studies of Nam and Tatum (1997) show that the role of principal architect/engineer and principal contractor is central in all innovations. According to the practice of WS Atkins, the principal architect/engineer will take the role as system integrators in this model. IPDB and VR will act as the major technical tools in the TPC paradigm. In this research, integrated project database (IPDB) is established as an integration of product models and process models. VR also plays an important role as an indispensable tool for improving communication. It becomes the main interface for all application packages and construction information for every specialty throughout the construction life cycle of the project.

In particular, the technical model needs to support information sharing and exchange among different function-specific software tools, and to develop efficient integration mechanisms. All participants in project installed different software in his computers, and there are so many available diversified tools in market, so limiting the clients to use compulsory tools is not realistic. This framework is intended to be tool independent, where tools can be integrated into the system without requiring change to the framework (plug and play).

If this framework were developed, all departments would either use the same software or employ a set of mutually compatible packages able to transfer data seamlessly between on function and the text.

Mechanism of the TPC adopting system
At present, the adopting of new IT technologies in both organizational and personal levels is not efficient, often poor. Organisations need to develop well thought-out strategies for moving to integrated systems. The effective implementation of large IT systems is not only a transition in tools and techniques, but also requires a substantial process and culture change.

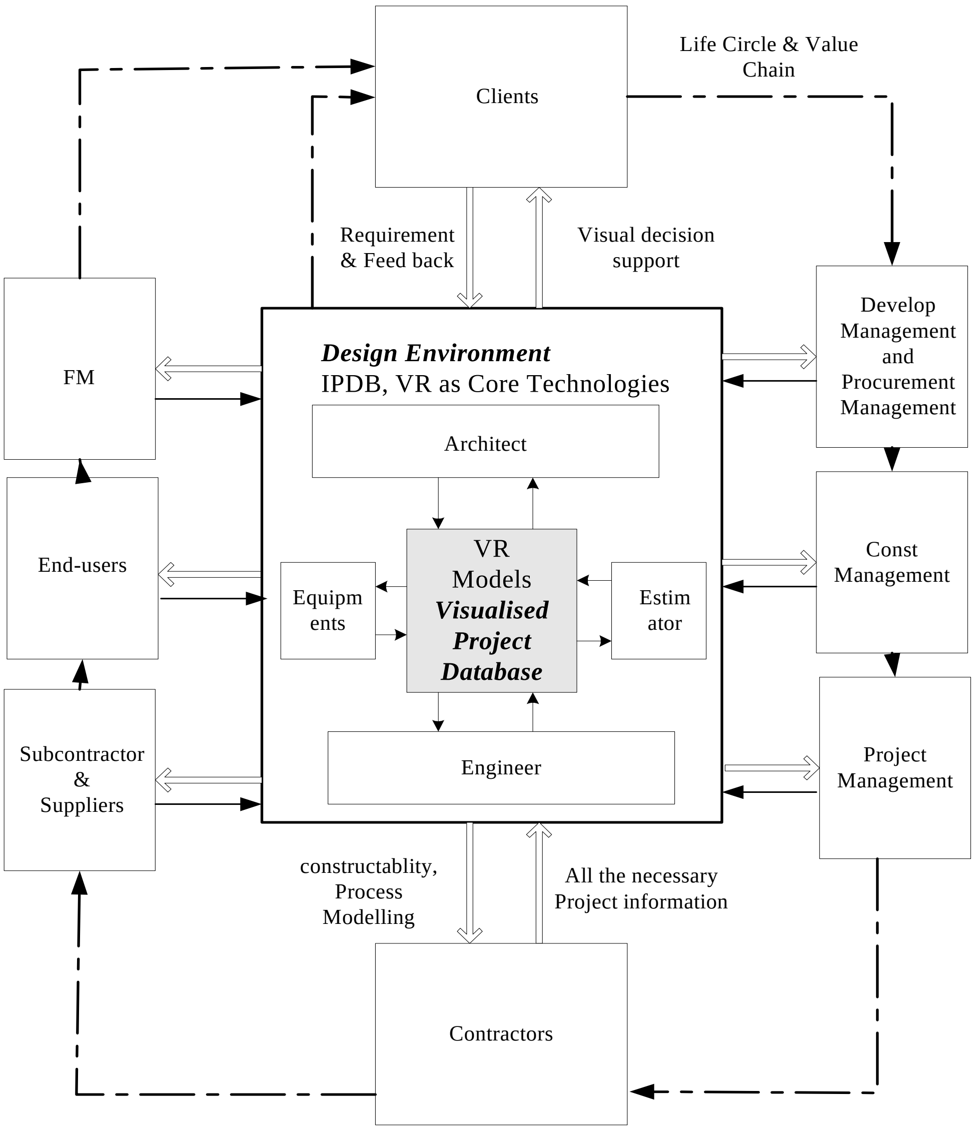

Figure 2 Integrated Visualised Project Database Model (Design-based)

Moreover, only by understanding the way that knowledge is disseminated within an institutional and culture context, it is possible to appreciate fully both the obstacles and practical solutions to the effective diffusion and application of knowledge between different disciplines or different sectors (Breshen and Marshall 2001).

Figure 3 developed by authors depicts how technology, process and culture interact each other. It also preliminary describes the mechanism of the adopting system and the understanding of knowledge management within context of the TPC paradigm.

According to developed TPC paradigm, the technology, process and culture are embedded in every project. Different from other systems, this research pays more attention to the culture. Each organization tended to have its own unique organizational culture and structure that frequently translated into significantly different work processes, information needs and information technology solutions. The culture acts as the foundation of the TPC model. At the same time, the formation of new innovative culture depends on the progress of technology, evolution and standardization of process. Process and technology are also impact on each other. For example, the technical framework is established based on specific business process employed by firms.

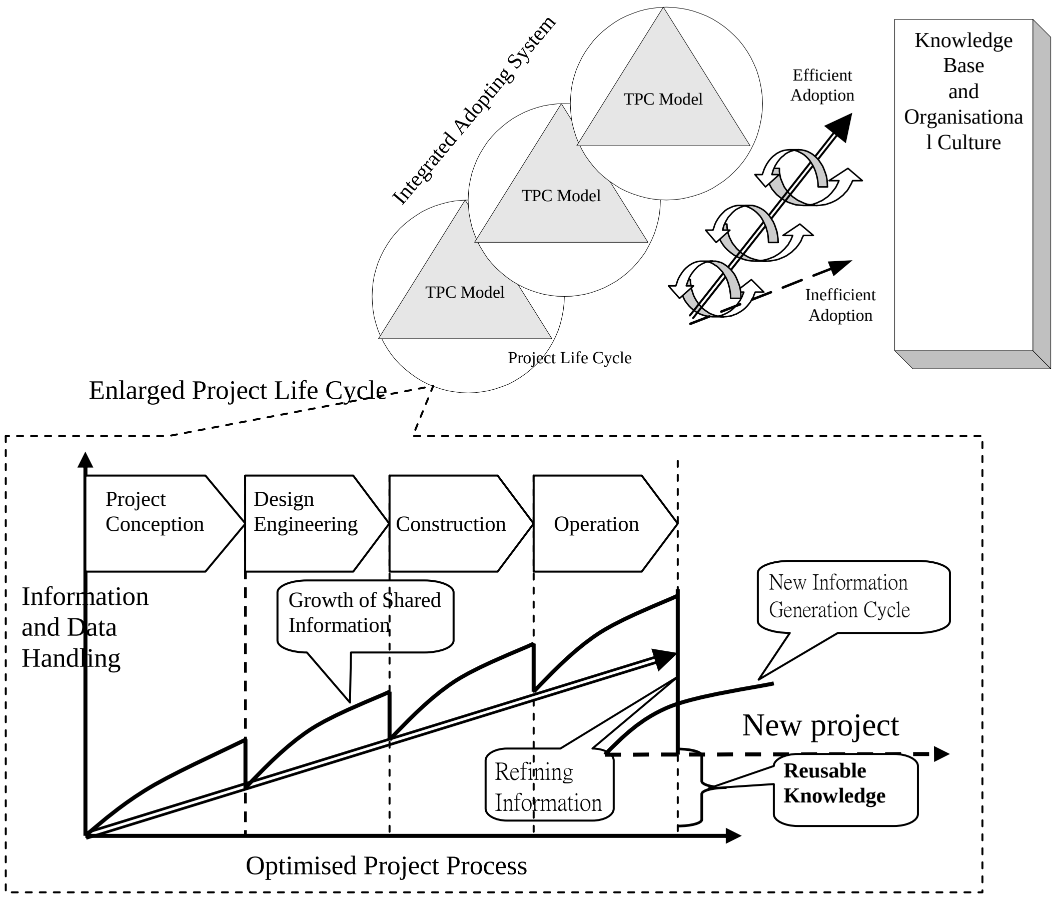

Figure 3 The Mechanism of the Integrated Adopting System

In this research, organisational culture is discussed, which place greater emphasis on shared experience and altitude to technologies and process, and knowledge base of a firm. In every project life cycle, the three factors interact and support each other. With the popular of innovative culture, the AEC firms will exploit the application of new technology and process to maintain their competitive advantages. Those firms will built their unique process and technical mechanism and apply they into every project they managed. Efficiency and effectiveness of those technical mechanism and process are continuously tested. The function of the culture is also measured in every project.

The interaction of three factors in a specific project enable information management facilities that can transfer, save, selectively drop, and distribute the project data to various project application during the entire life cycle of the project. At the end of the project, with refining the vast information and data accumulated in the project process, the reusable knowledge is elicited from integrated project database and introduced to next project. The spiral, shown in Figure 3, depicts the adoption as an iterative process whereby the industrial partners' and researchers' a priori knowledge, insights and experience form the projects, or common language, to form subsequently organisational culture and knowledge base, which include the knowledge of process, product and technologies and is a part of organisational culture.

Through the continuous iteration of project life cycle, suitable and dependable technology elicited and generic processes are established. They are gradually included in the knowledge base of the company and keep the relative stability. The AEC firms can get valuable benefits from the integrated adopting system.

The principle of tool and professional independent is employed in developing the technical model, so this system can be used in diverse projects, even at different project stage environment and participants are dramatically changed.

Project processes will become more certainly, and organized with good feedback loops. So the professionals have the opportunity to learn from project-to-project.

Optimised process in the TPC model will divide complicated processes into manageable chunks to aid the understanding of complex situations at different stage. In every project loops, the generic business process is analysed, and indispensable technology are elicited. Participants in a specific project can select its own basic technology and process. The process and technology are customized to the needs of a specific task, function or person and suitable for transaction from the view of different disciplines.

This corkscrewing procedure will create the ambience of efficient knowledge dissemination and the organizational culture conducive to innovation. Innovative Organisational culture will assist the organisational training and learning, so the firms can quickly and efficiently adopt the new technology and process.

The end users of project information including clients, contractors, building owners, FM managers, and other disciplines all can get knowledge and experience through the reuse and elicitation.

CONCLUSION

In the era of the knowledge economy, the quicker the new technologies are embraced, the better the position a company or industry will find itself in to compete at a world level. Integration technology will be a critical tool in efforts to improve both the communication and efficiency of the industry. Effective integration of design and construction for improved project performance requires shared the knowledge of design processes and products, construction processes, and the constraints faced by both. The dominant needs at this time are to rigorously study how these new technologies can impact industry, both in terms of best practices and consequences, and study how to adopt the technologies more efficiently. In this research, an integrated adopting system is proposed and tested in order to achieve full-fledged production automation under the control of a TPC framework. While this research would develop a specific standard and prototype of integrated adopting system, its broader impact would be through both the TPC triangle model and the individual development of a standardization process, VR, and IPDB application. The intention of this research is to maximise any possible benefit on AEC standardization and process improvement efforts. It will help the AEC firms to save time and money through seamless re-use of data between design tools, to improve quality through avoidance of mistakes otherwise made in re-keying data, and to resolve conflicts arising from different domains based on an ability to more easily identify and standardise. To accept those kinds of integrated adopting paradigm is much more difficult than to optimise supply flow, and improve the equipment utilized in project etc, because it require a significant reorganization and mind-shift of the fragmented industry. AEC companies can benefit from this integrated adopting system by a more efficient use of new evolving technology, appropriate process improvement and knowledge dissemination and interchange. It also provides alternative solutions for fragmentation, communications, knowledge dissemination problems, all of which have traditionally acted as barriers to improvement within the AEC sector.

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