NEW TECHNOLOGY DIFFUSION IN CONSTRUCTION: A CASE STUDY OF VIRTUAL CONSTRUCTION TECHNOLOGY (VCT)

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ABSTRACT

While most of the applications of Virtual Construction Technology (VCT) to date have been in the building and process engineering sectors of construction, it also has potential in major civil works. An Australian Project Based Engineering (PBE) firm has adopted VCT and applied it to three civil engineering projects over the last two years. A detailed case study of one of these, a toll way design and construct (D&C) project, is presented. The data highlights the implementation strategy used as well as some of the barriers to the diffusion of VCT in the construction industry. These results are interpreted in terms of Innovation Diffusion Theory and the factors involved in creating VC models to give a critical insight into the partial diffusion of VCT within a PBE firm.

The initial analysis suggests that even though VCT has been adopted by a PBE firm it cannot be successfully applied to projects, hence diffused into industry, unless the following conditions and the criteria for their achievement are met:

- Sufficient perceived benefit from on-site personnel exists
- A champion of the technology emerges on-site
- The nature of the technology is recognised and realised

The explanation and breakdown of these conditions as well as the future research directions resulting from their identification is a valuable contribution in the quest to better understand and improve the diffusion of VCT in the construction industry and new technologies in general.

KEY WORDS

innovation diffusion, virtual construction technology, technology adoption, construction

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INTRODUCTION

The rate of diffusion of new technologies in the construction industry is slow. This is due in part to experiences of negative effects on productivity with new technology introductions (Mitropoulos and Tatum 2000). Much has been written about the need to accelerate the rate of technological innovation in the construction industry (Mitropoulos and Tatum 1999).

Virtual Construction Technology (VCT) is a good example of a new technology that is currently in the early phases of diffusion in the construction industry. The potential value of VCT to construction projects is quite significant (Fischer, Haymaker et al. 2003; Katzer 2004) and it's diffusion in the industry is considered by most to be inevitable. However, this does not mean that this technology is diffusing readily or evenly. We need to better understand the drivers for the successful diffusion of new technologies like VCT.

Much of the past research has been based on a range of technologies (e.g. CAD, GIS, ICT) (Mitropoulos and Tatum 2000; Dooley 2001; Peansupap and Walker 2005) applied across a number of projects and data collection has been by means external to the projects. This paper focuses on one firm, the adoption of one technology within it and the implementation of that technology on one project.

There have been calls for more case studies on VCT implementations (Gao and Fischer 2005), methodological techniques beyond traditional methods (Larsen 2005) and research yielding short-term results (Katzer 2004). This paper reports on a case study that uses participant-observation to gain privileged access to the day to day workings of a project team and hence the process of adopting new technologies in live engineering projects. This approach of being embedded in the team yields insights not possible through methods such as surveys, interviews and external observation.

A brief review of relevant innovation diffusion literature and similar research is presented as well as background information on Virtual Construction (VC) modelling and the factors involved in the creation of VC models. The case study then provides empirical data for discussion and the findings are some conditions that need to be met for successful implementation of VCT in construction along with directions for future research. Another question arising from the literature (Mitropoulos and Tatum 1999) that this paper attempts to answer is; How the implementation strategy effects the success of implementation?

INNOVATION DIFFUSION IN CONSTRUCTION

CONCEPT DEFINITIONS

Adoption is the process by which an individual or organisation identifies and implements a new technology (Rogers and Shoemaker 1971). *Diffusion* is the process by which a new technology becomes accepted and used by its potential users (Mitropoulos and Tatum 2000). An *Innovation* is a new idea that is implemented in a project with the intention of deriving additional benefits although there may be associated risks and uncertainties (Ling 2003).

INNOVATION DIFFUSION THEORY

Everett Rogers "Diffusion of Innovations" (2003) is one of the most widely used theories on innovation diffusion. Figure 1 shows a brief overview of Rogers 5 stage innovation diffusion theory.

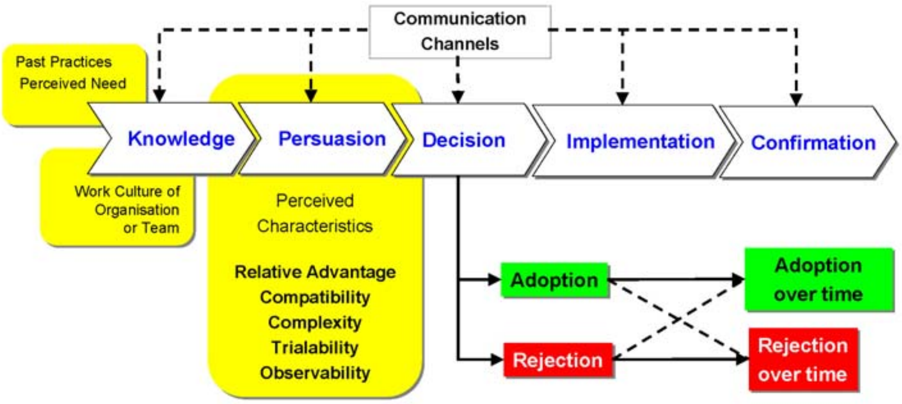

Figure 1: The Five Stages of Innovation Diffusion (Rogers 2003)

This model provides a framework of elements and mechanisms in the overall innovation diffusion process and is an ideal starting point that shows the bigger picture for a study focused on one particular part of the diffusion process. This paper focuses on the implementation stage but recognises the applicability of Rogers' model in the ultimate context of innovation diffusion.

IMPLEMENTATION FACTORS

For the implementation of an innovation to be successful, the decision makers associated with the adoption must understand the factors that effect implementation (Ensminger, Surry et al. 2004). These factors exist within three decision making levels: Industry or trans-firm Level; Organisation or intra-firm Level; and Project or inter-firm Level (Mitropoulos and Tatum 1999; Bossink 2004; Peansupap and Walker 2005).

Peansupap and Walker (2005) elaborated on factors influencing ICT diffusion into two of the three levels, inter-firm and intra-firm. Intra-firm factors involve the organisation itself such as management issues, individual issues, technical issues and work place environment issues. Inter-firm factors are focused on use issues and the dealings with external project members, consultants, sub-contractors and suppliers.

Stewart and Mohamed (2004) investigated the barriers to the diffusion of IT innovations that exist at the three decision making levels. At the industry level they found the barriers evident were cost concerns, poor leadership and industry fragmentation. Organisation level barriers were conservative practices with limited resources and a lack of perceived return on investment as well as resistance to change. Tight timeframes, security and privacy issues and again the fear of change were presented as project level barriers.

Bossink (2004) presents a summary of innovation drivers in construction networks by putting them into four categories and defining elements within the categories, they are;

Environmental Pressure (market pull and governmental clients with innovative demands); Technological Capability (technology fusion, technology leadership strategies and technology push); Knowledge Exchange (stimulation of research, broad view of risk, training of workers on the site and lateral communication structures); and Boundary Spanning (organisation and institution co-innovation, participant group coordination, empowerment of innovation leaders and champions and explicit coordination of the innovation process).

Effective leadership and decision making is essential for innovation diffusion - particularly in the construction industry. Technological competence and enthusiasm are important prerequisites of key individuals for effective leadership. One of the most critical roles of leaders is the delegation of the technical champion role and it can only be done with slack resources and adequate power (Nam and Tatum 1995). Champions exist at each decision making level of the diffusion process and they must all work together in a chain-like manner to ensure successful diffusion.

Opinion leaders, both formal and informal, and the communication networks within which they operate are also important factors to the success of an innovation implementation (Harkola 1995).

Implementation Strategies

Mitropoulos and Tatum (1999) found two general implementation strategies: (1) risk limitation in terms of consequences of failure; and (2) increased probability of success. The first strategy is pessimistic and reserved in most respects whereas the second sees a state of hyperactivity and participants going to great lengths to overcome any obstacle to ensure success.

VIRTUAL CONSTRUCTION MODELS

Virtual Construction (VC) models integrate design information with construction program information to produce a realistic visual model of a planned construction programme that can be interrogated by people from a diverse range of disciplines including clients. VC models are an enhanced form of 4D CAD through the addition of more realistic rendering and other representation to facilitate communication across disciplines. They comprise a major component of VCT.

After the initial model setup they can be easily updated with revised design or program information. This gives VC modelling the potential to capture design and planning intent or progress at all phases across the construction life cycle. However, this approach is yet to realise the maximum benefits it stands to provide in the construction industry.

KNOWN FACTORS INVOLVED IN CREATING AND IMPLEMENTING VC MODELS

Perhaps the most important input to any 4D CAD model is for all stakeholders to agree on the purpose of the model (Koo and Fischer 2002). This helps determine the level of detail the 3D data needs to have and what activities from the program will be used.

The relationship between the CAD data and the level of detail of the program also needs to be managed meticulously in order to arrive at a functional VC model. While an accurate 3D model may be readily available, this data still needs preparation for linking with the program. A major factor directly associated with this relationship that effects the modelling time and accuracy is the skill level of the 3D modeller and the efficiency with which the VC modeller works with the 3D model.

In order for a 4D CAD model application to realise the expected benefits to a project, the implementation needs to be planned and managed appropriately. Key controllable factors in this process are; understanding the modelling purposes, identifying the right timing, people, data, tools for doing it and putting them in the right workflow (Gao and Fischer 2005).

CASE STUDY: INTRODUCING VCT TO A MAJOR CIVIL D&C PROJECT

The context for this case study is a large infrastructure project being delivered through joint venture between two major Australian construction companies on a design and construct (D&C) basis. The case study is concerned with the introduction of VCT into this project in the form of a VC modelling effort that took place over 3 months. The VC modelling work was budgeted for in the tender submission so after award of the contract, at the time when program refinement was commencing, it was applied to the largest freeway interchange in the project. The rationale was that the VC model would benefit the project as a development tool for the planners by facilitating visualisation of the construction program for the major interchange. Its primary function was to aid in the resolution of spatial/temporal issues within the programme and a minor function was as an accessible, realistic 3D model of the design for all stakeholders.

RESEARCH METHODOLOGY

The method employed in this exploratory study was to embed a researcher as a participant observer within the D&C project office and also within the technical support team based in one of the joint venture partners. This technology team was championing the VC model through the entire lifecycle of its application. A web based data and communication management system was in place that facilitated transfer, tracking and archiving of all formal interpersonal communication and project data exchanges.

The following sections describe what was done and highlight the main observations from the project about the implementation stage of the technology diffusion process.

IMPLEMENTATION STRATEGY

Initially the researchers introduced the technology to the project planners on-site to gain local support and buy-in. Subsequently they helped in the major modelling effort (off-site) based on data supplied by the project team. They then worked with the project team on-site to further develop and use the model. Thus the VC model was introduced to the project using additional and also flexible resources. The technology manager on the project had full control of the creation, implementation and ongoing development of the VC model. The approval of VC modelling work by the planning managers on-site was the only constraint.

The model was installed in the planning section of the projects main office on a new computer dedicated solely to the operation of the VC model. One-on-one model interrogation training sessions, half an hour in duration, were held with 5 key personnel (4 planners and 1 planning manager) with the intention of producing at least 2 who could interrogate the model and thus become on-site champions of the technology.

BARRIERS TO SUCCESSFUL IMPLEMENTATION

Two of the four planners that underwent training for model interrogation were transferred to other projects within a month of the initial model set up excluding them as possible on-site champions. The reallocation of personnel also added to the initial modelling effort in two other circumstances whereby key decision makers who were already savvy with VC modelling were transferred and their replacements had to be introduced to the technology.

Email correspondence regarding the VC model shows that planning personnel weren't working with VC model development in mind. This is evident through slow response times to emails from the technology team requesting information as well as a constant concern that VC modelling would take away valuable time from normal responsibilities. Similarly, the emails also show how the cost of the VC modelling work was not of concern when compared to the concerns about the model realising its intended benefits. This was confirmed in model review meetings and formal discussions between the technology team and planning management as well as the field notes.

Informal communication networks provided a data source that indicated a low level of interest in the technology from project personnel – not sufficient enough to warrant the use of spare time from any participants hence the only time spent on the VC modelling effort was that approved by planning management. The VC model was generally seen as an extra-curricular activity, it was more important for personnel to get on with their usual work than to spend a lot of time becoming familiar with the VC model or the technology itself.

The data collected for input to the VC model and the gathering process was also a source that yielded some telling research data for analysis. Large amounts of time were spent by the technology team gathering data and when it was gathered the design was far more advanced than the construction program. Detailed activities existed for bridge constructions and traffic management however the activities for earthworks and road construction were lacking in detail. Mid-way through the 3 month period of VC modelling the planning management decided to outsource the construction of the interchange under study.

The main barriers to successful implementation encountered by this introduction of VC modelling can be summarised as; (1) Reluctance from personnel to engage in VC model activity; (2) The level of detail and availability of a construction program; (3) Insufficient perceived benefit from key personnel on-site.

DISCUSSION

DIFFUSION THEORY APPLICATION

Models presented in the literature for the diffusion of innovations can often be applied in different contexts and at different resolutions with respect to the one innovation diffusion. For example, the case study presented in this paper is a technology that is at the implementation stage of diffusion in the industry context. At the organisation level it is at the confirmation phase after already having found a place as a useful tool in the technology group. At the project level (this particular project) it is between the persuasion and decision stage of diffusion and, at the time of publishing, could still pass down the path of rejection in Rogers (2003) model.

In considering the three decision making levels from the literature it can be seen that the rate at which the technology passes through Rogers five stages is slowest in the industry context (decades), slightly quicker in the organisation context (years) and quicker again in the project context (months).

Another important context (shown by the data in this case), perhaps better tagged as an opinion or perception level, at an even lower resolution than the project level is the personnel context. An individual that comes into contact with the new technology can pass through the five phases (or indeed 3 and then rejection) in a matter of days after having had no prior knowledge of the technology. The low complexity of VC model interrogation and clear potential benefits thereof, both inherent to the nature of VCT, gives rise to this observation.

IMPLEMENTATION FACTORS INHERENT TO THE NATURE OF VC MODELLING AND VCT

The understanding gained by the researchers through participant observation and the data collected show VC modelling is different to most other technologies used as case studies in implementation research. Technologies like ICT, GIS and CAD all require adoption on mass by project personnel (or at least by more than one person) in order to recognize maximum benefits. If a VC model is constructed and maintained by a body external to a project site only one savvy operator needs to exist on-site to import updates and interrogate the model. By this deduction it can also be seen that data collection for implementation research into VC modelling focuses far more closely on individual key personnel, their perceptions of and resultant behaviour with respect to, VC modelling and VCT.

One of the main claims for the use of VCT is the ability to visually present the current state of a planned construction and when applied to a large infrastructure project it effectively shows the results of hundreds of man hours of work. Furthermore, if the VC model is constructed with sufficient intelligence it can be updated with revisions in CAD or program data in minutes and interrogated with simple navigation controls not beyond basic computer skills. It is conceivable that the existence of a medium that allows non-technical but highly influential stakeholders to assess the progress of hundreds of people in minutes, even if only to an indicative degree, would be quite intimidating to a lot of project personnel.

IMPLEMENTATION BARRIERS

VC modelling (and hence VCT) was already established in the technology group as a useful tool and approved in the projects tender budget, therefore common barriers to technology implementation found by Stewart and Mohamed (2004) (e.g. high costs and limited expenditure) were not witnessed. The nature of the group and the context within which it exists in the organisation was another major contributing factor to the ease of the initial implementation of VCT on the project. This is consistent with Bossink (2004). That is, the empowerment of the group manager along with the staff and resources available for committal.

Some of the ongoing implementation barriers that were encountered after the initial implementation also fit the literature. The reluctance of personnel to engage in VC model activity demonstrates aspects of three factors of Stewart and Mohamed's (2004) model, that being tight timeframes, security and privacy concerns and the ever present fear of change. An interesting variation to one of the factors in this model was the lack of perceived return on investment (or perceived benefit) being witnessed at the project level, in key personnel, rather than at the organisation level. The investment here however was one that was measured in time and not of monetary value, as the work was budgeted for and cost was not a major concern.

The reluctance of personnel to engage in VC model activity increased the time consumed by information gathering. The number of locations from which data inputs for the VC model had to come also increased the time spent gathering information despite the excellent standard of communication that existed, which was due in part to the web based data and communication system. The nature of the project (i.e. major civil D&C) and VCT (as discussed) are ultimately responsible for the existence of so many stakeholders and quite possibly the reluctance of personnel to engage in VC model activity.

The availability of a detailed construction program was an unexpected barrier encountered that couldn't be readily explained by the literature. The decision to outsource the program mid-way through the modelling effort provided another degree of separation between the model and planners creating the program. This could be viewed as a knock-on effect from the reluctance of personnel and people generally not working with VC modelling in mind.

These two barriers in many ways created the third as the time spent gathering information created periods of non-development for the VC model. These periods relate directly to the perceived benefit of the model by key personnel on-site due to the fact that all these personnel assumed observer rather than involved positions in the VC modelling effort. From the observers perspective it could be quickly and easily concluded that the model was not complete hence of no benefit. If there wasn't reluctance of personnel to be generally involved in VC model activity, a better understanding of the VC model and VCT may have spawned and the benefits of a model presenting a more detailed program could have been perceived. If one of the trained key personnel had approached the assumption of the role of site champion by occasional interrogation of the model and a showing of some interest in the technology a greater in-house push for model completion and use may have occurred. .

IMPLEMENTATION STRATEGY

The controllable factors set by Gao and Fischer in order for a 4D CAD model implementation to realise its benefits to a project were all addressed by the technology team. The purposes of the model were clearly set; the model was implemented at the time when the program for the major interchange was being developed; more than adequate resources were made available; and location of the model in the planning section of the site office placed it in the ideal position for integration into the workflow. This combined with the commitment and enthusiasm of the technology team shows an implementation strategy aimed at maximising the likelihood of success, thus consistent with Nam and Tatum (1995) and Mitropoulos and Tatum (1999). The implementation strategy delegated the role of on-site champion without success as a result of resource reallocations (in terms of personnel) and the reluctance of personnel as discussed above.

Despite an informed implementation strategy, there was an imbalance between the level of detail in the program and the 3D CAD data that was available for the design. The outsourcing of the programming work for the major interchange was the single factor that resulted in the unavailability of a sufficiently detailed program. Inevitably the model was not able to be taken to a state of maximum benefit and hence maintain a sufficient level of perceived benefit in key personnel.

CONCLUSIONS AND FUTURE RESEARCH

This paper provides some evidence of barriers that can exist to the diffusion of VC modelling (and indeed VCT) and compares them and the context in which they were investigated, the implementation stage of diffusion in the construction industry, to diffusion theory and similar research. The data indicates that the perceptions of on-site personnel are crucial to implementation success. The personnel decision making level, at a higher resolution than the project level, has been shown to be an important focus in the implementation of VC models at project sites. This insight was a result of recognising the nature of VCT. Recognition of the nature of VCT in an implementation strategy will help focus management directives (such as incentives) and help understand perceptions with respect to VCT.

The management and members of the technology team, as well as the project management responsible for inclusion of the VC modelling effort in the tender budget, provided all the champions required to get the technology to an initial implementation stage. Despite this and an informed implementation strategy striving to achieve success, none of the key personnel assumed the role of on-site technical champion after the initial introduction. As a consequence the model was virtually unused in periods without the presence of the technology team, and this was a critical missing link in the chain of project champions.

The benefits of the VC model to the project were perceived to be insufficient by the key personnel. This may have been avoided and the maximum benefits of the VC model recognised if on-site personnel had been working with VC model construction in mind by not making spontaneous resource allocations (in terms of work and personnel), spending more time familiarising themselves with the VC model and helping to minimise the time spent gathering information.

Future research following on from the findings in this paper should focus on parallels that exist in the implementation of similar technologies (i.e. those with advanced modelling capabilities) in construction projects along with informal communication networks and opinion leaders with respect to VCT implementations. This research will provide some triangulation as well as confirm the importance of the individual/personnel level of focus.

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