QUALITATIVE BREAKTHROUGH FOR INNOVATIONS IN COMPLEX ENGINEERING PROCESSES – A CASE STUDY IN CROSS-DISCIPLINARY RESEARCH APPROACH

RAHINAH IBRAHIM
Universiti Putra Malaysia, Malaysia

ABSTRACT

Malaysia building stakeholders need to mitigate the knowledge flows' problem is urgent since Malaysia has to prepare them for impacts of globalization when the services sector opens up in 2012. This paper is proposing an alternative approach to seek related solutions in a hard engineering study to understand how team members perform in their highly uncertain operating context. The paper illustrates an example cross-disciplinary mixed-method case study research methodology developed by combining research methodologies from the field of anthropology (ethnography), sociology (knowledge network analysis), and computer science and engineering (computational organizational theory—COT). It concludes that discontinuity in organizations is a factor in the K-loss phenomenon in property development where a discontinuous member's inaccurate knowledge cognition could cause a functional error at personal level that is not obvious at the enterprise's overall performance level. The paper outlines the engineering problem, presents theoretical points of departure, explains the mixed-method case study research methodology, and describes the results. In conclusion, it illustrates how the findings become foundations for current researches at Universiti Putra Malaysia.

Keywords: *Mixed-method Research Methodology, Dynamic Knowledge Flows, Organizational Behaviors, Integrated Design Management*

1. INTRODUCTION

This article describes how we can utilize qualitative research methodology in obtaining rich detailed information for solving an engineering problem. The study by Ibrahim (2005) was motivated by the need to extend the movement of tacit knowledge from individuals to other members of a property development team with *discontinuous membership*. She defined discontinuous membership as an organizational situation where a position in a project team is added or omitted as and when it is required during a workflow process. This type of study is becoming urgent since Malaysia's building stakeholders need to mitigate the knowledge flows' problem in order to prepare them for impacts of globalization when the services sector opens up in 2012. The case chosen as illustration was conducted in the context of property development within the construction industry in California, USA but the results can be generalized in many countries. The ultimate intent was to develop a flexible database system for the enterprise's knowledge management, which could capture both tacit and explicit knowledge during a property development life-cycle process in order to mitigate this knowledge loss (K-loss) phenomenon. The challenge was how researchers could develop such a user-friendly knowledge management system that captures the inherent tacit knowledge of individuals or the enterprise. However, in order for the study to reach the higher goal, it must first understand why K-loss is still recurring despite measures by project sponsors to invest in information technology to help curb the loss. While recent construction researches have successfully enabled American general contractors to maintain their profit margins during construction phase, more efforts are needed to mitigate development cost increment during the pre-construction design process. Studies have found that a majority of reasons for these cost

increments are due to inefficient knowledge movements between members of a project team (Jin & Levitt, 1996).

An initial literature comparison by the study reveals three viewpoints—namely the city's (Landis, 2001), the property developer's (Ibrahim, 2001), and the architect's (AIA, 1997)—to see whether the three parties match in their definitions of a property development process. It suggested a dual side scenario in the property development process prior to the construction phase: *the well-known Architectural-Engineering-Construction design-construction process versus the developer's public and financing process*. It was in this uncertain period that the study identified it as the period during which, most of the K-loss occurrences start manifesting in the property development process. Further literature analysis against *contingency theory* (Burton & Obel, 2003) framework allowed the study to categorize the property development life cycle operating *environment* as having high complexity, high uncertainty, and high equivocality environmental characteristics. Despite having a functional organizational configuration, it has high complexity because the property development organization also reflects a strong matrix configuration with multiple interdependencies between workflow processes. Although it has a general sequential development activity schedule property development, the project has high uncertainty because project managers cannot accurately predetermine which workflow path they need to concentrate on at any given time. The operating environment has high equivocality due to existing multiple and conflicting interpretations, confusion, and lack of understanding among the stakeholders. These are apparent especially when dealing with regulatory agencies, city officials, and the public.

The intricate environmental characteristics pointed to the need for a detailed research on how we could ensure the transfer of decisions and information (i.e., knowledge that enables the enterprise to act) from one team to another efficiently while the process progresses, and allowing project sponsors to maintain the project's feasibility. Hence, an alternative qualitative research approach was conducted to understand how team members perform in their highly uncertain operating context prior to the development of advanced tools and methodologies to mitigate this K-loss phenomenon. This paper presents how qualitative research was used in identifying the source of K-losses in complex engineering processes that impact financial and schedule losses.

Utilizing data from the affordable housing domain, a mixed-method case-study research methodology was developed combining research methodologies from the field of anthropology (ethnography), sociology (knowledge network analysis), and computer science and engineering (computational organizational theory—COT). The knowledge network analysis utilizes the Knowledge Asset Mapping Exercise (KAME; Palazzolo, 2005) instrument customized based upon ethnographic and computational modeling research (Ibrahim & Nissen, 2007), and additional consultation with the respective project manager. A pre-KAME interview protocol (Palazzolo, 2005) provides information regarding the key knowledge areas, key tasks, and the assignment of various team members during the phases of the selected project. On the other hand, COT is developed when certain computational analysis founded on organizational theories becomes a tool for extending current organizational theories. The SimVision® software was utilized in this study (refer http://www.epm.cc/ for details). The paper outlines the engineering problem, presents theoretical points of departure, explains the mixed-method case study research methodology, and describes the results. In conclusion, it illustrates how the findings become foundations for current researches at Universiti Putra Malaysia.

2. BACKGROUND LITERATURE

The study focused on the possible period—i.e., the entitlements and building permit phases—where Ibrahim (2005) believed that K-loss started manifesting during a property development life cycle. It focused on the pre-construction phase. In this section, we present the summary of the literature gap, and illustrate how the study positions itself within the knowledge flows field and in its broader context. Figure 1 adapted (Nissen, 2002) *notional knowledge-flow* three-dimensional vector representational model that enables researchers to visualize an enterprise's knowledge flows. The global goal of knowledge flow is expediting individual tacit knowledge to the inter-organizational explicit knowledge. The knowledge flow path is not a straight line, as was established by Nonaka (1994) in his *spiral model*, and by Nissen's (2002) *knowledge flow trajectory*.

Referring to Figure 1, the first dimension is the epistemological dimension defining the explicitness of knowledge. Polanyi (1967) was first to look at the epistemological definitions of knowledge and divided it into tacit and explicit (y-axis). Nonaka (1994) developed the ontological reach (x-axis) when he proposed the spiral SECI trajectory (socialization, externalization, combination, internalization) as tacit and explicit knowledge amplified from individual to group to organization to inter-organization. The third dimension of knowledge flow is its life cycle.

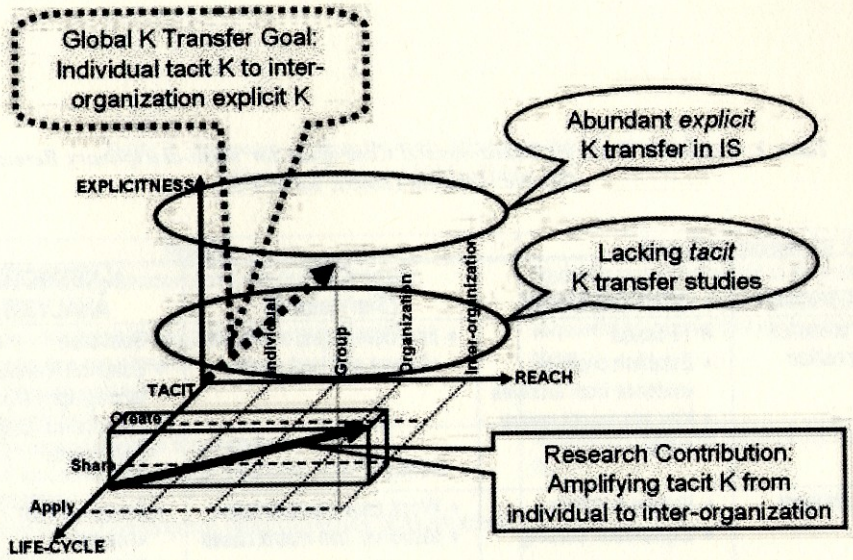

Figure 1: Research contribution to dynamics knowledge-flow theory by amplifying tacit knowledge from individual to inter-organization (Adapted from Nissen (2007); Ibrahim (2005), Fig. 1-1).

Table 1: Mixed-method Case-study Steps for Multi-disciplinary Research (Source: Ibrahim (2005), Table. 1-2)

STEP	RESEARCH QUESTION	RESEARCH METHOD (Tool/ Source)	UNIT OF ANALYSIS	OBJECTIVES	LIMITATIONS ON CHOICE OF METHOD
1	How does K flow across the life cycle phases of a complex process?	Ethnography (Archival)	Enterprise	-Understand life cycle process from owner's view. -Identify potential K-loss reasons.	Does not measure K flows.
2	What are the operating environmental constructs that are representative of how K flows in a complex process with discontinuous membership?	COT (SimVision®)	Enterprise	-Develop integrated K flows and organizational environmental constructs. -Cross-validate life cycle environment in COT tool.	Only at theoretical level because data for measurements are not possible yet.
3	How different are the K flows within a life cycle phase of a complex process?	Knowledge Network Analysis (KAME)	Individual	-Determine whether there are different K flow behaviors among team members.	Does not link to workflow process.
4	How do K-flows impact the organizational performance in enterprises with discontinuous membership?	COT (VDT-KN)	Project	Answers research question!	Only proof-of-concept. Need further studies to determine exact behavior parameters.

Table 2: Validation Tests for Mixed-method Case-study for Multi-disciplinary Research (Source: Ibrahim (2005), Table 1-3)

TYPES	METHODS	ETHNOGRAPHY	COT (SimVision®)	K-NETWORK ANALYSIS	COT (VDT-KN)
CONSTRUCT VALIDITY	Data collection Composition	• 13 cases • Establish chain of evidence from archives • Key informants review drafts	• Interview project managers of worst and best cases.	• Best case • Establish K areas from ethnography study • Determine K mapping participants	• Conceptual case • Use K areas and K perceptions of project members from knowledge network analysis.
INTERNAL VALIDITY	Data Analysis	• Pattern matching • Explanation building	• Worst case representation • Matrix vs. non-matrix cases	• Social network analysis • Multiple linear regression • Individual level	• Pattern matching with expected results. • Establish chain of evidence
EXTERNAL VALIDITY	Research Design	• Compare with Environmental Factor in *Contingency theory* [6] • Compare with California's planning fees structure [3]	• Integrate dynamic K flows theories in model building. • Compare with Environmental Factor in *Contingency theory* [6]	• Compare with *Transactive Memory Theory* [19] • Compare with *Collective Action Theories* ([20], [21])	• Integrate *transactive memory theory* [19] in VDT model. • Compare results with expected outcomes from *transactive memory theory* [19]
RELIABILITY	Data Collection	• Able to use key events and documents to gather data on remaining 60 cases	• Replicate worst and best cases while maintaining environmental factor affects • [18] representational model	• Duplicate KAME on other facility development projects.	• [18] intellective experiments

Table 3: Summary of Results from Mixed-method Case-study
(Source: Ibrahim (2005), Table 1-4)

Research Method	Results	New Propositions for Future Research
ETHNOGRAPHIC STUDY	Identification of operating environmental constructs for facility development: 1) Multiple concurrent and sequential life cycle phases 2) Discontinuous membership 3) Task interdependency 4) Knowledge form	Discontinuous membership in an enterprise promotes K-loss when a work process has multiple, interdependent, concurrent and sequential processes that are handling varying K-types in each phase.
COT (SimVision®)	Additional organizational design fit parameters: 1) *Reach* for contingency design parameter fit for properties configuration. 2) *Discontinuous* for contingency design parameter fit for structural configuration. 3) *Knowledge* for contingency factor for situation fit.	*Knowledge* is another contingency factor for organizational design fit.
KNOWLEDGE NETWORK ANALYSIS	Characteristics of K flows in sequential phases of a facility development life cycle: 1) In K areas where tacit K dominates, *continuous experts* tend to retrieve and contribute their information to and from others. 2) In K areas where tacit K dominates, *discontinuous experts* tend to retrieve and contribute their information to and from other team members whom they perceive to be more continuous. 3) In K areas where explicit K dominates, *functional experts* tend to retrieve and contribute information to and from other experts.	*Transactive Memory* for the facility development domain: Communication to Allocate Information: The process by which agents who *have* information from the environment, on topics *outside* their own areas of expertise, determine which other agents in the network *could benefit* from this information, and pass the information on. Communication to Retrieve Information: The process by which agents who *know they could benefit from other experts'* information coordinate the retrieval of information from those they perceive as being the most appropriately skilled experts.
COT (VDT-KN)	Impacts of discontinuous membership on organizational performance: development life cycle: 1) Macro level: Improvements on simulated duration and cost, but 'negligible' change to total work volume. 2) Micro level: Increase of waiting period, but reduction in coordination period.	Knowledge networks among team members can promote non-hierarchical knowledge flows that improve the organizational performance of an enterprise with discontinuous membership. But the success of such knowledge flows depends on the accuracy of each team member's meta-knowledge about the skills of other team members, and discontinuous membership reduces the accuracy of this meta-knowledge.

Nissen (2002) extended the dynamics of knowledge flow theory Nonaka (1994) by integrating the life-cycle process of knowledge flow through the enterprise when he amalgamated from other scholars' knowledge life cycle steps (Davenport & Prusak, 1998; Depress & Chauvel, 1999). He developed a six-step life cycle process for knowledge: 1) creation, 2) organization, 3) formalization, 4) distribution, 5) application, and 6) evolution. In this vector model, Nissen (2002) fourth dimension is how the flow time occurs for the knowledge movement. This flow time can represent the 'stickiness' of the knowledge flow within the enterprise. Von Hippel (1994) coined the term 'stickiness' on how a needed information can 'stick' with the problem-solving capabilities in a different location, which Szulanski (2000) further developed the 'stickiness' measure of knowledge during its transfer process within an organization. Concentrating much on the knowledge sharing aspect of the life cycle stages, the figure illustrates that much of knowledge transfer literature is currently in the upper end of the epistemological scale—i.e., explicit—where knowledge can be stored, retrieved, and used. It is in the lower end of the epistemological scale that the case study intends to contribute.

3. CROSS-DISCIPLINARY MIXED-METHOD CASE STUDY

The study utilizes a mixed-method case study research methodology that was developed by Yin (2003) with the development of transdisciplinary inputs. In order to answer the main research question, i.e., how do knowledge flows impact the organizational performance in enterprises with discontinuous membership; several sub-research questions were developed. Table 1 listed the research questions, the corresponding research methodologies, their respective unit of analyses, research objectives, and the limitations of that particular choice of method. Table 2 summarizes the validation tests that followed Yin (2003) four-step validation process for each research methodology used in answering a specific research question. They are construct, internal, external, and reliability validities. A summary of the results from the mixed-method case study is detailed in Table 3. For each research methodology, we present the results and new propositions that were developed for future research.

4. CONCLUSIONS AND FUTURE STUDIES

The study by Ibrahim (2005) has several implications that stem from better understanding of knowledge flow issues in respect of current organization design. First, it affirmed that the property development enterprise, which has a combination of complex, uncertain, and equivocal environmental characteristics, would always incur knowledge loss because of its environmental characteristics. Unless researchers understand the impacts of discontinuous membership on the enterprise, the K-loss phenomenon will stay with the construction industry forever. Second, discontinuous organization is not explicitly considered in the organizational configurations and parameters laid out in Burton & Obel's (2003) *contingency theory*. Organizations with discontinuous membership fall between *ad hoc* and *matrix* configurations, and without any design recommendations. Based on the study, an additional seventh contingency factor—*knowledge*—was proposed to be included in the diagnosis and design of organizational fit (Ibrahim & Nissen, 2007). Additional measures are *reach* and *discontinuous* for design parameter property and structural configuration respectively (ibid.). Third, current organization design is strongly based on Galbraith's (1974 and 1977) information-processing theory. Following the validation trajectory proposed by Thomsen, Levitt, Kunz, Nass & Fridsma (1999), the study "intellectively" proposes—i.e., with idealized models of work processes and organizations—that the property development enterprise also has a non-hierarchical information-processing system that can affect organizational performance. Moreover, both hierarchical and non-hierarchical knowledge flows are very much governed by the dominant knowledge type—i.e., tacit vs. explicit—in a given project phase and whether or not the team member is "continuous"—i.e., present in successive workflow phases—or discontinuous. Current and future studies founded on these results include developments of theories and emerging computer-integrated applications for enhancing the movement of knowledge in complex design and construction processes using industrialized building systems (IBS).

Currently, a number of postgraduate researches are reviewing the construction industry delivery process in order to develop a systemic methodology (Ibrahim, 2009) to mitigate the K-loss phenomenon. Focus is on the tasks and periods where the multi-disciplinary task interdependencies occur within the complex multiple sequential and concurrent workflows. Concentrating on the 3D delivery process instead of the conventional 2D documentation method, the researches emphasize the integration of IT/ICT into the 3D modular coordinated process that supports the IBS Roadmap 2003-2010 and the Construction Industry Master Plan 2006-2015. With emphasis on the design phase of the property development process, among the research projects include study on enhancing the professional behavioral aspects of the eastern culture (Pour Rahimian, Ibrahim & Jaafar, 2008), ensuring sustainability of spatial linkages during the dynamic conceptual design process (Hosseini & Ibrahim, 2007),

and ensuring socio-economic sustainability in property development (Bakhtiar & Ibrahim, 2007). Future studies also include development of design theories to enhance knowledge flows in project teams (Ibrahim & Fay, 2006; Ibrahim & Baharuddin, 2007), and design assessment of modular-coordinated building.

5. ACKNOWLEDGEMENTS

This is an extended paper presented at the Malaysian Science and Technology Conference 2007 in Kuala Lumpur on 4-6 September 2007.

6. REFERENCES

American Institute of Architects. (1997). Abbreviated standard form of agreement between owner and architect. *AIA document B151-1997*. New York: The American Institute of Architects.

Bakhtiar, B., & Ibrahim, R. (2007). Identifying affordable quality housing components for developing a smart growth model. *ALAM CIPTA, Intl. J. on Sustainable Tropical Design Research and Practice,* 2: 41-48

Burton, R. M., & Obel, B. (2003). *Strategic organizational diagnosis and design: Developing theory for application*. Boston: Kluwer Academic Publishers.

Davenport, T. H., & Prusak, L. (1998). Successful knowledge management projects. *Sloan Management Review,* 37: 53-65.

Depress C., & Chauvel, D. (1999). Mastering information management: Part six- knowledge management. *Financial Times* (8 March): 4-6.

Galbraith, J. R. (1974). Organization design: An information processing view. *Interfaces,* 4: 28-36.

Galbraith, J. R. (1977). *Organization Design*. Reading, Massachusetts: Addison-Wesley.

Hosseini, A.G., & Ibrahim, R. (2007). Using Social Network Analysis for Visualizing Spatial Planning during Conceptual Design Phase. *Proceedings of the 12th Computer-Aided Architectural Design Research in Asia 2007* organized by University of Sydney and Nanjing University in Nanjing, China April 19-21.

Ibrahim, R., & Fay, R. (2006). Enhancing Cognition by Understanding Knowledge Flow Characteristics during Design Collaboration. *ALAM CIPTA, Intl. J. on Sustainable Tropical Design Research and Practice*, 1: 9-17.

Ibrahim, R. (2001). *Feasibility of 4D CAD in design development and approval process for affordable housing*. Engineer Diss., Department of Civil and Environmental Engineering, Stanford University.

Ibrahim, R. (2005). *Discontinuity in organizations: Impacts of knowledge flows on organizational performance*. Doctoral Diss., Department of Civil and Environmental Engineering, Stanford University.

Ibrahim, R. (2009). "Integrating BIM in workflow- Issues and Challenges." Paper presented at the International Conference on Building Information Modeling in Architecture (BIMARC2009) organized by FutureARC in Kuala Lumpur 19-20 Aug.

Ibrahim, R., & Nissen, M. E. (2007). Discontinuity in organizations: Developing a knowledge-based organizational performance model for discontinuous membership. *International Journal of Knowledge Management,* 3: 18-36.

Ibrahim, R., & Baharuddin, N. (2007). Marrying Communication System and Knowledge Flows Theories in Conveying Design Meanings to the Society. *Proceedings of the 2nd International Conference on the Arts in Society* organized by CommonGrounds at University of Kassel, Germany August 21-24.

Jin, Y., & Levitt, R. E. (1996). The virtual design team: A computational model of project organizations. *Computational and Mathematical Organization Theory* 2: 171-196.

Landis, J. (Ed) (2001). *Pay to play: Residential development fees in California cities and counties, 1999*. Department of Housing and Community Development, Division of Housing Policy Development, California.

Marwell, G., & Oliver, P. (1993). *The critical mass in collective action: A micro-social theory*. Cambridge, UK: Cambridge University Press.

Monge, P. E., & Contractor, N. S. (2003). *Theories of communication networks*. Oxford, UK: Oxford University Press.

Nissen, M. E. (2002). An extended model of knowledge-flow dynamics. *Communications of the Association for Information Systems,* 8: 251-266.

Nonaka, I. (1994). A dynamic theory of organizational knowledge creation. *Organization Science,* 5: 14-37.

Palazzolo, E. T. (2005). Organizing for information retrieval in transactive memory systems. *Communication Research,* 32: 726-761.

Polanyi, M. (1967). *The tacit dimension*. London: Routledge and Keoan Paul.

Pour Rahimian, F., Ibrahim, R., & Jaafar, M. F. Z. (2008). Feasibility study on developing 3D sketching in virtual reality (VR) environment, *ALAM CIPTA, Intl. J. on Sustainable Tropical Design Research and Practice* 3: 93-103

Szulanski, G. (2000). The process of knowledge transfer: A diachronic analysis of stickiness. *Organizational Behavior and Human Decision Processes,* 82: 9-27.

Thomsen, J., Levitt, R. E., Kunz, J. C., Nass, C. I., & Fridsma, D. B. (1999). A Trajectory for Validating Computational Emulation Models of Organizations. *Journal of Computational & Mathematical Organization Theory,* 5: 385-401.

Von Hippel, E. (1994). "Sticky information" and the locus of problem solving: Implications for innovation. *Management Science,* 40: 429-439.

Wegner, D. M. (1987). Transactive memory: A contemporary analysis of the group mind. Edited by B. Mullen, and G. R. Goethals. *Theories of Group Behavior*. New York: Springer-Verlag, 185-208.

Yin, R. K. (2003). *Case-study research: Design and methods*. Thousand Oaks: Sage Publications, Inc.