UNIVERSITI PUTRA MALAYSIA

COLLABORATIVE EXPERIENCE-BASED FACTORY MODEL FOR SOFTWARE DEVELOPMENT PROCESS

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By

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January 2019

Chairman : Professor Rusli bin Abdullah, PhD
Faculty : Computer Science and Information Technology

A key aspect in software development (SD) is the management of its knowledge and experiences. Since many decades ago, organizations have been valuing the experiences and know-how of their employees. One of the frameworks that enables learning and continuous improvement is the Experience Factory (EF) framework. Yet, previous literatures have reported that EF is hard, costly, and risky, and requires considerable amount of effort to implement. Although there are several evolutions on this framework over the years, however, the works have been declining in the recent years due to the unwillingness of the organizations to invest and due to the unclear benefits to the employees. In addition, knowledge management (KM) issues in SD still persist until today and software organizations are still striving to learn from previous experiences.

This dissertation proposes a model for managing SD knowledge and experiences based on the EF approach, namely EBF-SD, to address the limitations of EF as well as to overcome the KM issues for SD process in a collaborative environment. The proposed components are SD Process Knowledge Base, Community of Practice Influences, Knowledge Management Process Enablement, and Technology & Infrastructure Support. In order to implement EF, its goals must be clarified and measurable, thus, the components are evaluated against the EF goals.

Qualitative methods such as expert review and pilot study are conducted to verify the initial conceptual model, while quantitative method is used to investigate the relationships between the components and EF goals. Data reliability and construct validity are examined via Rasch Analysis and Factor Analysis, while hypothetical relationships are examined using correlational analysis, multiple linear regression and Partial Least Squares of Structural Equation Modeling (PLS-SEM).

Empirical study indicates that the components have positive and significant relationships towards EF goals whereby 6 out of 7 hypotheses are supported. Empirical evidences also reveal that technological support is the main significant factor towards the achievement of EF goals. Based on these findings, a prototype is developed to translate the model into a working system, as a proof-of-concept, by implementing the proposed components into appropriate functionalities and relevant technological approaches. Evaluation of the prototype via descriptive statistics and PLS-SEM reveals that the prototype is beneficial and significantly contributes to the achievement of EF goals. Other findings suggest that knowledge quality has higher influence in terms of system usage and user satisfaction as compared to system quality.

The overall research findings demonstrate that the proposed model is adequate, significant and accepted by the software practitioners in the context of collaborative software development environment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGALAMAN KOLABORATIF BERASASKAN MODEL PENGILANGAN BAGI PROSES PEMBANGUNAN PERISIAN

Oleh

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Aspek utama dalam pembangunan perisian (SD) adalah pengurusan pengetahuan dan pengalamannya. Sejak beberapa dekad lalu, organisasi telah menilai pengalaman dan pengetahuan pekerja mereka. Salah satu rangka kerja yang membolehkan pembelajaran dan peningkatan berterusan adalah *Experience Factory* (EF). Tetapi, EF adalah sukar, mahal, dan berisiko, dan memerlukan banyak usaha untuk dilaksanakan. Walaupun terdapat beberapa evolusi pada rangka kerja ini, bagaimanapun, kerja-kerja tersebut telah berkurangan pada tahun-tahun kebelakangan ini disebabkan oleh keengganan organisasi untuk melabur dan juga kerana manfaat yang tidak jelas kepada pekerja. Di samping itu, isu pengurusan pengetahuan (KM) di dalam SD masih berterusan sehingga hari ini, dan organisasi perisian masih berusaha untuk belajar dari pengalaman sebelumnya.

Disertasi ini mencadangkan satu model untuk mengurus pengetahuan dan pengalaman SD berdasarkan pendekatan EF, yang dinamakan EBF-SD, untuk menangani kekurangan EF dan juga untuk menangani isu-isu KM yang sedia maklum bagi proses SD dalam persekitaran kolaboratif. Komponen yang dicadangkan adalah Pangkalan Pengetahuan Proses SD, Pengaruh Pengamalan Komuniti, Pengayaan Proses Pengurusan Pengetahuan, dan Sokongan Teknologi & Infrastruktur. Untuk melaksanakan EF, matlamatnya mesti dijelaskan dan boleh diukur, oleh itu, komponen-komponen dinilai terhadap matlamat EF.

Kaedah kualitatif seperti tinjauan pakar dan kajian perintis dijalankan untuk mengesahkan model konseptual awalan, dan kaedah kuantitatif digunakan untuk menilai hubungan antara komponen dan matlamat EF. Kebolehpercayaan data dan kesahihan konstruktif diperiksa melalui Analisis Rasch dan Analisis

Faktor, manakala hubungan hipotetis diperiksa menggunakan korelasi, regresi linear berganda dan Model Persamaan Struktur Separa Paling Rendah (PLS-SEM). Kajian empirikal menunjukkan bahawa komponen mempunyai hubungan positif dan signifikan terhadap matlamat EF di mana 6 daripada 7 hipotesis disokong.

Bukti empirikal juga mendedahkan bahawa sokongan teknologi adalah faktor penting yang utama ke arah pencapaian matlamat EF. Berdasarkan penemuan ini, satu prototaip dibangunkan untuk menterjemahkan model ke dalam sistem kerja, sebagai bukti konsep, dengan melaksanakan komponen yang dicadangkan ke dalam fungsi yang sesuai dan pendekatan teknologi yang relevan. Evaluasi prototaip melalui statistik deskriptif dan PLS-SEM mendedahkan bahawa prototaip ini memberi manfaat dan memberi sumbangan besar kepada pencapaian matlamat EF. Penemuan lain menunjukkan bahawa kualiti pengetahuan mempunyai pengaruh yang lebih tinggi dari segi penggunaan sistem dan kepuasan pengguna berbanding dengan kualiti sistem.

Penemuan keseluruhan menunjukkan bahawa model yang dicadangkan adalah mencukupi, penting dan diterima oleh pengamal perisian untuk pembangunan perisian di dalam persekitaran kolaboratif.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AVE	Average Variance Extracted
C_COLL	Communication and Collaboration
CC	Cloud Computing
CONTENT	KM Content Process
CoP	Community of Practice
CR	Composite Reliability
D&M	DeLone and McLean
EBF-SD	Experience Based Factory Model for Software Development Process
EBF-SD-Q	EBF-SD Questionnaire
EBF-SD-KMSQ	EBF-SD Knowledge Management Success Questionnaire
EF	Experience Factory
EF_GOALS	EF goals
EF_ORG	EF Organization
EFA	Exploratory Factor Analysis
ESEM	Enterprise Software Engineering Model
FA	Factor Analysis
GSD	Global Software Development
HOC	Higher Order Construct
IEEE	Institute of Electrical and Electronics Engineers
IS	Information Systems
IT	Information Technology
J&O	Jennex & Olfman
K_ORG	Knowledge Organization
K_SHARE	Knowledge Sharing Community
KM	Knowledge Management
KMO	Kaiser Meyer Olkin
KM_FORM	KM Form
KM_LEVEL	KM Level
KM_PROC	Knowledge Management Process
KMSS	Knowledge Management System Success
KQ	Knowledge Quality
LINK	Linkage
LOC	Lower Order Construct

LR	Literature Review
LVS	Latent Variable Scores
MAS	Multi-agent Systems
MGMT	Management Influences
MLR	Multiple Linear Regression
MNSQ	Mean square
NB	Net Benefit
NIST	National Institute of Standards and Technology
OKC	Organizational Knowledge Creation Theory
ORG_CL	Organizational Culture Influences
ORG_MGMT	Organizational and Managerial Level
OWL	Web Ontology Language
PLS-SEM	Partial Least Square Structural Equation Modeling
PT_SM	Portal and Social Media
PTMEA CORR	Point measure correlation
PCA	Principal component analysis
PIDM	Person Item Distribution Map
PLS	Partial Least Square
PROJ_ORG	Project Organization
QA	Quality Assurance
RA	Rasch Analysis
RICH	Richness
RMM	Rasch Measurement Model
RQ	Research Question
RUP	Rational Unified Process
SAT	User Satisfaction
SD	Software Development
SDP	Software Development Process
SDLC	Software Development Life Cycle
SECI	Socialization, Externalization, Combination, Internalization
SEM	Structural Equation Modeling
SLR	Systematic Literature Review
SPEM	Software Process Engineering Meta-Model
SQ	Software Quality
SWEBOK	Software Engineering Body of Knowledge

TECH	Technological and Infrastructure
TECH_RES	Technological Resources
TECH_SUP	Technological Support
TVE	Total Variance Explained
UI	User Interface
UML	Unified Modelling Language
USE	Intent to Use/Perceived Benefit
VAF	Variance Accounted For
VIF	Variance Inflation Factor

For all of us to win in the knowledge economy, we need to unleash the knowledge in our document databases, use and reuse our past knowledge, find ways to create new knowledge and then share it across our enterprise. In the digital, networked age, knowledge is our lifeblood. And documents are the DNA of knowledge.

~ Rick Thoman, President and CEO of Xerox in 2000

CHAPTER 1

INTRODUCTION

1.1 Background

In today's digital world, software development (SD) has become a major and prominent field. Undeniably, a lot of processes, events, activities and best practices are involved while developing software; this would result in continuous production of usable knowledge and experiences either in explicit or in tacit form. However, valuable knowledge and experiences are often lost when organizations are being re-structured or when employees leave the projects. In learning organizations, the collection of best practices and lessons learned enhance and harness individual and team learning that already occur in the organization; however, many organizations miss the opportunity to take its valuable advantage because the information is often lost and not captured in a timely manner as it is being gained (Vandeville, 2000). It is known that the problems of scattered and unmanaged knowledge and experiences have existed since decades ago and continue to be challenging until today (Ackoff, 1989; Alavi & Leidner, 1999; Mahroeian & Forozia, 2012; Abbariki et al., 2017; Heredia et al., 2018).

Knowledge Management (KM) is a value-added to organizations in such a way that it encourages innovation, maximizes profits, and improves decision making by means of knowledge and information sharing among the people working within the organization (Mohsen et al., 2011). Managing knowledge and experiences are crucial in organizations in such a way that it prevents knowledge loss and making it less dependent on its employees, it unloads, elicits, and stores experts' experience and make it available, it creates productive employees sooner, and it improves the business process (Basili et.al, 2001a). Additionally, global or distributed development has been the current trend to many organizations due to the competitive advantages for shorter time to market, better resource usage, increased productivity, and reduced costs (Chaves et al., 2010). Nevertheless, for distributed software development, KM challenges are even more crucial (Ivarsson & Gorschek, 2012; Huzita et al., 2012; Ardimento et al., 2012); and therefore, collaborative knowledge management has becoming more imperative and significant (Yahia et al, 2012; Stapel & Schneider, 2014; Rocha et al., 2014).

Experience Factory (EF) (Basili et al., 1994a; Basili et.al, 2001a) has been one of the prominent framework in software process improvement which focuses on organizational learning. Organizational learning is mainly driven by three essential organizational processes in KM: maintaining learning loops in all processes, systematically disseminating knowledge throughout an organization, and applying knowledge wherever it can be used in an organization (Sanchez, 2005). Prior research has suggested that it is important for organizations to continuously learn in order to stay competitive and improve performance (Chouseinoglou et al., 2013; Ras & Weber, 2009; García-Morales et al., 2012).

This dissertation explores the EF infrastructure, its concept and limitations, and it proposes how this framework could be enhanced and applied in a collaborative SD environment to overcome the issues of managing knowledge and experiences in SD process.

1.2 Problem Statement

Literature has reported that the Experience Factory framework has several limitations (Houdek, 1999; Bartlmae & Riemenschneider, 2000; Tautz, Althoff, & Nick, 2000; Basili et al., 2001b; Schneider et al., 2002; Ivarsson & Gorschek, 2012). The original EF model itself is abstract and conceptional -- it requires defining clear and specific goals, tasks and processes of the involved agents and installing an appropriate technological platform (Houdek, 1999 as cited by Bartlmae & Riemenschneider, 2000). The model is claimed as hard to implement, risky and costly, and it requires a significant investment of time and efforts to capture, organize, package and distribute knowledge (Basili et al., 2001b; Schneider et al., 2002; Ivarsson & Gorschek, 2012). The realization of EF concepts for software process posits challenges from characterizing what constitutes a process experiences, how can it be captured, documented and stored to institutionalizing effective mechanisms to select the most relevant experience from the knowledge base (Tautz, Althoff, & Nick, 2000 as cited by Kamel et al., 2002). It is also not clear how the additional knowledge activities (i.e. capture, organize, package, and distribute knowledge) would benefit the employees; and thus, the management are often not willing to invest (Basili et al., 2001b).

In the meantime, previous studies have reported that knowledge management issues in SD have existed since many decades ago (Ackoff, 1989; Mahroeian & Forozia, 2012; Abbariki et al., 2017), especially on the inefficiency of knowledge transfer and information flow in organization (Salger et al., 2010; Wongthongtham & Kasisopha, 2011; Stapel & Schneider, 2014). The collaboration gaps due to the diverse communication styles, technical equipment, and missing awareness of each other (Stapel & Schneider, 2014), and the difference in background, culture, terminology, practices and standards being used (Salger et al., 2010; Wongthongtham & Kasisopha, 2011), would also lead to problems such as missing knowledge context interpretation and inconsistencies. Information from various discussions, e.g. emails and meetings, are not well documented, and they are kept in silence (Stapel & Schneider, 2014). Moreover, as supported by several researchers, inefficient knowledge transfer between teams may happen due to inefficient communication, diverging cultures, high complexity, and lack of project management; therefore, knowledge are kept localized between individuals or teams, and they are not shared or made accessible (Ivarsson & Gorschek, 2012; Rocha et al., 2014; Ardimento et al ., 2013).

In the field of software engineering, there are still lack of studies dealing with organizational learning (Menolli et al., 2013). Additionally, several studies have documented that organizations are still struggling to learn from past experiences (Stapel & Schneider, 2014; Wende et al., 2013; Gino & Staats, 2015). Previous best practices and experiences are not utilized, teams repeatedly make the same mistakes, repeatedly re-invent the wheel, and consequently, software development productivity, quality and cost are affected (Stapel & Schneider, 2014; Wende et al., 2013). Continuous improvement requires commitment to learning; however, learning failures occur when companies fail to draw important lessons from crises and to preserve their memory in the organization (Bazerman & Watkins, 2004), when they focus too heavily on success, are too quick to act, try too hard to fit in, and rely too much on experts, which eventually undermine continuous improvement (Gino & Staats, 2015).

1.3 Research Questions

Based on the research problems discussed above, there is a need to leverage alternate approaches to distribute and share knowledge within the SD community, as well as to establish learning organizations effectively by realizing the knowledge management process. Specifically, this research proposes leveraging the Experience Factory framework in the context of collaborative software development process. Thus, the following research questions are formed:

- RQ1: What can be achieved (goals) from the experience factory in the context of knowledge and experience management in software development process?
- RQ2: What are the relevant components that support the experience based factory model for software development process in collaborative environment?
- RQ3: How to ensure that the experience factory goals are achieved based on the proposed model?
- RQ4: How to ensure that the experience factory goals are achieved based on the proposed prototype?

1.4 Research Objective

The main goal of the research is to develop a model to manage knowledge and experiences of software development process that is able to support collaborative environment. Thus, the following underlines the detail objectives:

- To analyze the relevant components that are able to support knowledge and experience management in a collaborative software development process.

- To propose a model based on experience factory approach to support knowledge and experience management in collaborative software development process.

- To translate the model into a working prototype and evaluate the prototype with the model objectives.

1.5 Research Significance

The study is significance in SD industry based on several reasons. First, this study is relevant as according to the current trend of software development whereby distributed development is more desired, and furthermore, KM in this context is more challenging (Herbsleb & Moitra, 2001; Ivarsson & Gorschek, 2011; Huzita et al., 2012; Ardimento et al., 2012). With a defined process of KM based on EF framework, this proposed model will improve the knowledge transfer and sharing among the distributed teams.

Second, the model proposes reusing of products, processes and experiences from past projects which eventually will provide the opportunity to build a quality system at a lower cost (Basili et al., 1994a). By packaging existing experiences of SD process, project teams and individuals will be able to know what the software has gone through during its life cycle, and this will make the knowledge transfer become more effective. Reusing of products, processes and experiences originating from the system life cycle provides the opportunity to build a quality system at a lower cost achieved by reusing and modifying over and over the same elements and learning from direct experience (Basili et al., 1995).

Third, this model will benefit software organizations by providing learning platform, i.e. by collecting SD processes, structuring and making them available (Basili et al., 2001b). In learning organization, EF has been long used as one of the organizational learning as well as for software process improvements (Basili & Caldiera, 1995; Flores Rios & Rodríguez-Elias, 2010; Koennecker et al., 2000). With an EF implementation, the SD processes are collected, structured and made available for further improvement or reuse. It supports closed-loop process in which evaluation and feedback are available for the purpose of project control and learning (Basili et al, 1995).

And last but not least, the model will be helpful to organizations as the past experiences can be used as guidance for them to make correct decisions on the well-defined set of products -- to satisfy customer needs, to assist developers to accomplish those needs, to define the right processes and to improve the overall software development (Basili et al., 1994a).

1.6 Research Scope

This research is conducted on the basis of developing a model to manage knowledge and experiences for software development process in a collaborative environment based on experience factory approach. The base framework chosen is the Experience Factory framework (Basili et al., 1994a). This framework is selected for this study because of its strong foundation in software process improvement and it had been implemented in several international organizations for the purpose of software improvement and systematic learning (e.g. Software Engineering Lab (SEL), Q-Lab Inc., Daimler Benz AG, an Australian telecommunication company) in the past decades.

The development of the base components for the model are based on literature study and feedback from the experts. The model validation is established with the empirical data collected from the SD community on their perceptions (agreeableness) on the model formulation. The proposed model is then validated for its correctness through a series of relevant statistical analysis methods. Further, a prototype is developed and evaluated to demonstrate the capabilities of the model.

The context of the SD process model implemented in the prototype is limited to two software process models: the Waterfall model (sequential approach) and Scrum framework (agile approach). This is adequate to demonstrate the SD process model as the prototype knowledge base.

1.7 Thesis Organization

The thesis organization is structured into eight chapters. Chapter 1 discusses the background of the study, problem statement, research questions, objectives, significance and scope.

Chapter 2 details out the reviews of the literature that cover the important theoretical frameworks and concepts. This includes topics on software development process, KM concepts, SD process, experience factory, and further technological support as well as the influences from organizational and managerial perspective.

Chapter 3 describes the research methodology carried out in this research. It describes the methods involved during literature review, model development, and model validation via empirical study as well as via a working prototype. The analysis of expert review and pilot study are described in this chapter. Further approaches on data analysis, descriptive and empirical analysis, are described profoundly.

Chapter 4 discusses the detail development of the conceptual model including how the components are derived based on the research gaps, and how the whole model is formulated based on the identified components. It also includes the description on the hypothesis development.

Chapter 5 presents the empirical results of the model validation and the detail discussions about the findings. This include the model reliability and fitness, factor analysis, correlational analysis, multiple linear regression and PLS-SEM analysis. The final model is presented based on the findings.

Chapter 6 describes the development of the proposed prototype by first identifying the right functionalities and technological approaches based on the validated and finalized model. The prototype system requirement specification, design and implementation are also described.

Chapter 7 presents the results interpretation from the empirical findings and the results obtained from the prototype evaluation. Discussions include the hypothesis testing results and implications.

Chapter 8 concludes the research study as well as discusses about the theoretical and practical contribution, limitation of the study and directions for future research.

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Mastura Hanafiah is a software practitioner that is now working with Mercedes-Benz Malaysia Sdn. Bhd. Her current role is as a product owner for the automotive company focusing on digital channels for electric vehicles. She has involved in all phases of software development process including project management, requirement analysis, design, implementation and testing, both in traditional software process lifecycle models as well as in agile environment. She has many years of experience in Java software development mainly for custom software development and maintenance in various domains e.g. health, e-government and automotive. She obtained the degree of Computer Science from Washington University in St. Louis, MO, USA and holds a Master Degree in Software Engineering from University Malaya (UM). Her current research interests include knowledge management, information retrieval, big data analytics, ontology development, multi-agent systems and software engineering. In 2014, she started pursuing PhD in Information Systems at the Faculty of Computer Science and Information Technology, Universiti Putra Malaysia (UPM). Her research has appeared in International Review on Computers and Software, Advanced Science Letter, Journal of Theoretical and Applied Information Technology and Journal of Telecommunication, Electronic and Computer Engineering.

LIST OF PUBLICATIONS

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