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MULTI-METHODOLOGICAL APPROACHES IN DESIGN SCIENCE: A REVIEW, PROPOSAL AND APPLICATION

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Abstract

Multi-methodological research approaches have been strongly recommended for adoption to guide information systems (IS) research and deal with the complexities involved in the research. These research approaches require appropriate mapping and integration of multiple research methodologies. However, this is not an easy task to accomplish due to a series of philosophical, cultural and psychological issues involved. By reviewing and analyzing existing representative multi-methodological design science approaches, we identify that each approach has its own strengths and weaknesses. There is a clear gap between the need of multi-methodological approaches and the support from the existing research frameworks. To address these problems and issues, we propose an integrated multi-methodological research framework, which integrates strengths of the representative multi-methodological approaches and remedies their deficiencies. We demonstrate the application of the proposed framework by applying it to guide a research project in the field of information visualization, and discuss how the framework is deployed to address research problems/issues/requirements and fulfill research objectives.

Keywords: Multi-methodological Research Framework, Design Science, Research Methodology, Research Output, Application

1 INTRODUCTION

Information systems (IS) research is complex and dynamic in nature. It involves diverse research areas such as the design, development and use of general and specific information systems, and the impact of deploying information systems in organization and society. Also, it produces a variety of research artefacts, for example, underlying models, tools, languages, system components and applications. Furthermore, it could incorporate different dimensions of real world situations, materials and dynamic social and personal research contexts. Such complexities involved in IS research could deteriorate the effectiveness of applying a single methodological approach to develop conclusive solutions to a certain research problem. Compared to single-methodological approach, integrating and adopting multiple research methods can be more beneficial to IS research because each involved research method produces positive complements to others, and benefits of the integrated research approach are greater than the sum of those of its parts (Nunamaker et al., 1991; Burstein & Gregor, 1999; Mingers, 2001; Cao et al., 2006). For instance, based on the study of a computer-based detection deception system, Cao et al. (2006) proved the existence of such positive interactions and complements, and demonstrated the benefits of a multi-methodological approach through examining how system evaluation activities may interact with theory testing activities. When a multi-methodological approach is selected and adopted appropriately, researchers may achieve a better understanding of the research problem and validated research outcomes, and conduct a more effective IS research.

Although the complexities involved in IS research tend to require the use of appropriate multi-methodological approaches, mapping and integrating multiple research methods is not easy to accomplish. Mingers (2001) identified four typical problems with applying a multi-methodological approach, that is, philosophical problems (e.g. paradigm incommensurability), cultural problems like the negative effect of particular organizational culture that disturbs the implementation of a certain multi-methodological approach, psychological problems such as difficulties about some researchers feeling uncomfortable with adopting multiple research approaches, and practical problems.

Furthermore, by reviewing representative multi-methodological IS research frameworks, we identified that each research framework has its own strengths and weaknesses. For example, with Nunamaker et al.'s (1991) multi-methodological approach, researchers could adopt a set of research methods for each involved research strategy so as to produce more convinced outcomes. However, this research framework lacks a clear indication that a research process is generally initiated with observation. It also fails to incorporate considerations about the underlying research environment such as characteristics of the involved people/organization(s)/technologies and their impact on the research. More details of the strengths and weakness of representative multi-methodological research frameworks are presented in the subsequent section.

There is a clear gap between the need of multi-methodological approaches and the support from the existing research frameworks. This motivates us to design and develop a research framework integrating the strengths of representative multi-methodological research frameworks and remedying their deficiencies.

This paper has three essential objectives. Firstly, it aims to highlight the strengths and weaknesses of existing representative multi-methodological research approaches. Secondly, it intends to propose a multi-methodological design science research approach that integrates the strengths of the representative approaches and addresses their deficiencies. Thirdly, this paper attempts to demonstrate how the proposed multi-methodological approach can be applied to guide an IS research project.

This paper is organised as follows. In section 2, we review the existing representative multi-methodological research approaches and analyze their strengths and weakness. To address the weaknesses associated with these approaches, we design and propose a multi-methodological design science research approach in section 3. Then, in section 4, we discuss the application of the proposed research approach through leveraging it to guide our research in defining, designing and developing purposeful visualizations and purposeful visualization systems.

2 A REVIEW OF MULTI-METHODOLOGICAL DESIGN SCIENCE APPROACHES

Multi-methodological research approaches have been strongly recommended for guiding IS research. Some existing representative approaches are Nunamaker et al.'s (1991) multi-methodological approach, March and Smith's (1995) two-dimensional research framework, Hevner et al.'s (2004) IS research framework, and Adams and Courtney's (2004) DAGS framework. In this section, we review and examine the strengths and weaknesses of these multi-methodological approaches. This section also sheds a light on how our proposed multi-methodological design science approach is developed.

2.1 Nunamaker et al. (1991)

To guide IS research activities, Nunamaker et al. (1991) introduced a multi-methodological research framework which is composed of four mutually complementary research strategies, that is, observation, theory building, systems development and experimentation. Observation aims to achieve a good understanding of the interested research problem and domain as well as provide support for tasks involved in other research strategies, for example, helping with the formation of new hypotheses to be tested for the experimentation strategy. Theory building strategy is to guide the design and development of new concepts, models and frameworks. When a new theory is developed, researchers can adopt experimentation and system development strategies to examine, validate and refine the theory. Among these research strategies, the systems development strategy plays a pivotal role by interacting with other strategies and linking them together.

To illustrate how this approach can be applied to guide IS research, Nunamaker et al. (1991) proposed a five-step system development oriented research process. It starts with identifying and understanding a research problem, and then proceeds to develop system architecture that requires researchers to identify and define system development goals, core system components and functionalities and interactions among these components. The following step is to analyze the requirements for implementing the architecture, for example, understanding the underlying implementation domain, selecting appropriate technologies for the implementation, designing alternative solutions and defining evaluation criteria to choose the most appropriate alternative. With keeping the requirements in mind, researchers develop prototypical system(s) to validate and refine the proposed theory and system designs, and then assess the prototype(s) against pre-defined research and system development objectives. Such evaluation results can influence their understanding accumulated at previous steps, which, in turn, may initiate a new iteration of the system development process.

Strengths and Weaknesses

A key strength of Nunamaker et al.'s (1991) framework is that the involved strategies can produce mutually complementary research outcomes, if used appropriately. For instance, a prototype, developed by following the system development strategy, may contribute to the validation of the theory proposed by applying the theory building strategy. Furthermore, Nunamaker et al.'s (1991) approach involves systems development as its central research strategy. Burstein and Gregor (1999) pointed out that a research process including systems development tends to be more complete, comprehensive and dynamic. Systems development method has also been recommended for IS studies by many researchers, such as Nunamaker et al. (1991), Parker et al. (1994), Morrison and George (1995), and Burstein and Gregor (1999). It can even bridge the gap between the technological and the social sides of IS research (Burstein & Gregor, 1999).

Besides the above strengths, the design of Nunamaker et al.'s (1991) research framework is flawed on three counts. First, it lacks a clear indication that a research process is generally initiated with observation. Researchers and practitioners should first carefully observe real world problems before they can progress to other research tasks such as deriving and defining a research problem, building theories for addressing the problem, and developing and evaluating a prototype to validate and refine the theory. Second, their framework fails to incorporate considerations about the underlying research environment such as characteristics of the involved people/organization(s)/technologies and their

impact on the research. These characteristics and impacts may significantly affect the selection of methods for implementing each research strategy. Third, this framework is presented inappropriately in the sense that the four strategies are demonstrated with inconsistent focuses. The observation strategy is accompanied with possible research methods (e.g. case, survey or field studies) and the same thing applies to the experimentation strategy. However, the systems development strategy is presented with only possible research activities (e.g. prototyping or technology transfer), while the theory building strategy just outlines potential research outputs (e.g. conceptual frameworks, methods or models). This brings difficulties to identify and differentiate research methods, activities and outputs for each research strategy. This framework could be better organized through deploying an appropriate and consistent presentation pattern.

Despite the above deficiencies, Nunamaker et al.'s (1991) research framework is still a good starting point for us to develop our proposed approach. To seek ways to address its deficiencies, we continue to review other representative multi-methodological approaches in the following sections.

2.2 March and Smith (1995)

The two-dimensional IT research framework, proposed by March and Smith (1995), has a particular focus on highlighting common research activities and outputs involved in IS research. March and Smith (1995) opined that IS research is actually a combination of design science and natural science. Therefore, how well the research activities involved in design and natural sciences are performed determines the relevance and effectiveness of IS research. March and Smith (1995) identified four general research activities (i.e. build, evaluation, theorize and justify) and four broad types of research outputs (i.e. constructs, models, methods and instantiations). By integrating these research activities and outputs together, they developed this two-dimensional research framework that consists of sixteen cells with different research objectives, efforts, methods and evaluation strategies.

Strengths and Weaknesses

As the building blocks of March and Smith's (1995) framework are high-level generalizations of research activities and outputs, this framework itself is a conceptual framework and thus inappropriate to be used to provide practical guidance for conducting IS research. However, compared to Nunamaker et al.'s (1991) framework presenting research strategies with different levels of details, March and Smith's (1995) framework demonstrates a good way to present potential research activities and outputs involved in IS research. This further motivated us to apply March and Smith's (1995) framework to examine and analyze IS research adopting strategies involved in Nunamaker et al.'s (1991) framework. We identified that employing each research strategy may occupy multiple cells in March and Smith's (1995) framework, i.e. conducting a set of research activities and delivering certain research outputs. For example, the potential research activities and outputs in implementing systems development strategy are illustrated in Figure 1.

		Research Activities			
		Build	Evaluate	Theorize	Justify
Research Outputs	Construct			Proposing a new concept	Proving the validity of the concept
	Model			Defining system components and their core functionalities; Developing a system architecture	Justifying the validity of system components & the entire system architecture
	Method			Developing a method	Proving the validity of the method
	Instantiation	Building a prototypical system	Evaluating the prototype		

Figure 1 Research activities and outputs involved in the implementation of systems development strategy

2.3 Hevner et al. (2004)

Building on top of March and Smith's (1995) IT research framework, Hevner et al.'s (2004) developed a conceptual IS research framework to integrate two mutually complementary research paradigms, that is, behavioral science and design science. This research framework involves three essential building blocks, i.e. research environment, IS research, and knowledge base. Among them, the research environment outlines how business requirements for addressing a certain problem should be defined, evaluated and positioned within the underlying problem context. The IS research component demonstrates the way of how behavioral science and design science paradigms may complement each other and fulfill the business requirements through developing/justifying theories and building/evaluating artefacts. Such theories and artefacts are designed and developed based on the materials available in the knowledge base. This framework aims to assist researchers with understanding IS research, provide fundamental principles for guiding IS research, and illuminate the way to achieve relevant, effective and rigorous IS research.

Strengths and Weaknesses

Different from March and Smith's (1995) framework, a key strength of Hevner et al.'s (2004) research framework is that it provides a comprehensive view of environmental factors that may impact on IS research. Building on the research of Silver, Markus and Beath (1995), Hevner et al. (2004) identified three broad categories of research environmental factors, that is, people, organization and technology. Understanding such environmental factors and their impacts can bring more practical guidance for conducting IS research and produce more effective solutions to particular business needs. The strength of Hevner et al.'s (2004) framework exposes an opportunity to address the weakness that Nunamaker et al.'s (1991) framework fails to incorporate the impacts from the underlying research environment. Furthermore, similar to March and Smith's (1995) framework, Hevner et al.'s (2004) framework tends to provide little practical guidance on how to conduct IS research.

2.4 Adams and Courtney (2004)

Building on the research of Nunamaker et al. (1991), Adams and Courtney's (2004) proposed a DAGS framework, which involves four research methodologies, i.e. design science, action research, grounded theory and systems development. Among them, design science and grounded theory are adopted for building theories while systems development and action research are utilized to aid in testing and refining the theories. This DAGS framework expands partial components in Nunamaker et al.'s (1991) framework (i.e. observation, theory building and systems development) and realizes them by leveraging action research and grounded theory. More specifically, grounded theory is applied to implement the theory building strategy while action research is adopted to implement the observation strategy. Being in consistent with Nunamaker et al.'s (1991) framework, this DAGS framework also treats systems development as the core component and utilizes it to connect other involved methodologies together. However, the DAGS framework seems not involve any research methods to realize the experimentation strategy of Nunamaker et al.'s (1991) framework.

Strengths and Weaknesses

The DAGS framework reinforces the importance of including systems development into a research framework to guide IS research. It also attempts to present a way to instantiate Nunamaker et al.'s (1991) framework. However, it deserves to be pointed out that involving design science as a component in the framework is quite confusing. This is because design science actually includes observation, theory building, systems development and experimentation (Peffer, Tuunanen, Rothenberger & Chatterjee, 2008). In other words, design science already covers everything described in Nunamaker et al.'s (1991) framework. Therefore, it is not appropriate to claim that the design science approach in the DAGS framework is merely used for theory building. In addition, theory formation tends to be inappropriate to be included in systems development since it is just one step involved in theory building processes.

3 AN INTEGRATED MULTI-METHODOLOGICAL DESIGN SCIENCE RESEARCH APPROACH

Building on the research of Nunamaker et al. (1991), we propose an integrated multi-methodological research framework, which remedies the deficiencies associated with Nunamaker et al.'s (1991) framework by integrating the strengths of other representative research frameworks (Figure 2). This integrated research approach aims to assist with the development of practical research frameworks that integrate a set of mutually complementary research methodologies. As illustrated in Figure 2, framework comprises three presentation layers, that is, research strategies, research methods, and research outputs.

The research strategies layer outlines the high-level research strategies that may be adopted for conducting IS research. These strategies are observation, theory building, system development and experimentation, which are consistent with the strategies of Nunamaker et al.'s (1991) framework. Different from their framework, this integrated framework clearly indicates that IS research should start from careful observations of real world problems. The observation strategy is concerned with deploying appropriate research methods (such as case studies, survey studies or field studies) to achieve a good understanding of the interested research problem(s) and domain(s). Based on the understanding of the problem(s), researchers may apply the theory building strategy to define and develop new ideas, concepts, conceptual frameworks, models or methods. When a new theory is developed, they may adopt system development and experimentation strategies to examine, validate and refine their theory. With systems development, researchers design, develop and implement appropriate prototypical systems to validate their proposed theory. Experimentation can be conducted by employing, but not limited to, computer simulations, laboratory or field experiments in order to facilitate the development and refinement of the proposed theory, system designs and implementations.

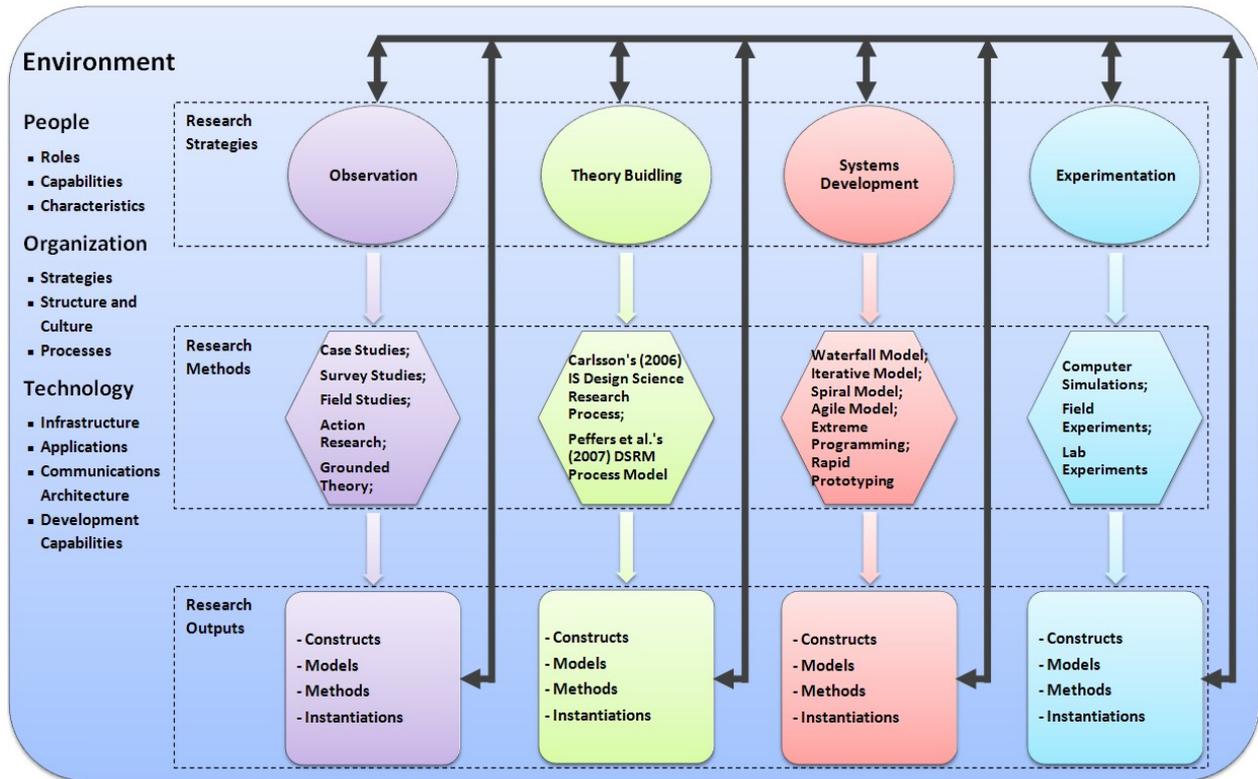


Figure 2. An integrated multi-methodological research framework

Unlike Nunamaker et al.'s (1991) framework, this integrated framework presents research strategies in a clear and consistent manner. To realize the strategies, the research methods layer shows possible methods that can be adopted to implement the related strategies, as illustrated in Figure 2. At this layer, researchers need to select appropriate research methods and specify the corresponding research processes/activities. The expected outcomes to be achieved by implementing each research method are presented at the research output layer. The idea of realizing and presenting research strategies in such way is inspired by the DAGS framework.

Furthermore, the integrated framework incorporates Hevner et al.'s (2004) environmental factors that may affect how researchers and practitioners identify, define, interpret and address research problems and requirements. It also integrates the research output categorization of March and Smith's (1995) framework and classifies research output into four categories: constructs, models, methods, and instantiations. In addition, the double sided arrows connecting research outputs with research strategies indicate the mutual complements among the implementations of multiple research strategies.

To apply this integrated research framework to guide IS research, it needs to be instantiated by selecting relevant research strategies, adopting/developing appropriate research methods and defining the expected research outputs. This is discussed with a real IS research project in the subsequent section.

4 APPLICATION OF THE PROPOSED MULTI-METHODOLOGICAL APPROACH

To demonstrate the usage of the proposed integrated framework, we apply it to our research project about designing, developing, applying and evaluating visualizations to address the complexities involved in visualization problems and contexts and to maintain visualization effectiveness under contextual changes. This section provides a brief overview of our research project and focuses on discussing the instantiated research framework.

4.1 Background of Research Project

With the rapid advances achieved in the field of information visualization, visualization techniques and applications have been widely adopted in various domains/disciplines to help people explore, get insights from, and/or interpret large volumes of data and to inform/shape/change/ reinforce their mental models and behaviors. Visualizations are created with a particular purpose for one or more stakeholders within a certain context. When the purpose, context or stakeholders change over time and domain, the effectiveness of the visualizations can vary accordingly. To emphasize the importance of context and purpose when we design/implement/apply/evaluate visualizations, we define such visualizations as purposeful visualizations (PV). Furthermore, visualization problems nowadays often involve increasingly high complexities that may emerge from tremendous data volumes, combined data types, the need of integrating multiple visualizations, visualization evaluation, and/or multiple combined paradigms/domains. These problems and issues significantly exacerbate the difficulties involved in developing flexible and effective visualizations. They also require visualizations to be flexibly created, instantiated, manipulated, customized, integrated with other visualizations, executed and modified.

While existing visualization techniques and systems tend to provide reasonable support for particular paradigms, domains and data types, they are weak when it comes to addressing the above flexibility requirements and changing visualization purposes/contexts/stakeholders. To address the above problems, issues and requirements, we initiated a research project to (1) explore and formally define the concept of purposeful visualizations, (2) construct models to facilitate understanding/analyzing/evaluating PV, (3) develop a process to guide the application of PV for addressing various visualization purposes in the domain of visual decision making, and (4) introduce and design purposeful visualization systems (PVS) to support the creation/instantiation/manipulation/integration/execution/evaluation/modification of PV. To prove the validity of the proposed concepts, models, frameworks and architectures, we implement a vertical PVS prototype in a flexible and reusable fashion.

To obtain practical guidance for our research, we instantiated the proposed integrated framework and discuss it in the following section.

4.2 The Instantiated Research Framework

To instantiate the proposed integrated framework, we selected all four research strategies for the project, adopted a set of research methods to implement each strategy and specified our expected research outputs from research strategy implementations (Figure 3).

Observation

The observation strategy is adopted to achieve a thorough understanding of our research problems and domain. It also aids in the analysis and evaluation of the proposed artefacts within various visualization contexts. Literature review, case study and semi-structured interviews are adopted to realize this research strategy. More specifically, to formally define PV, we reviewed and synthesized the extant literature on information visualization from six essential perspectives, that is, visualization stakeholders, purposes, contexts, visualization techniques, visualization evaluation, and visualization systems. For each perspective, we identified a set of visualization problems and issues and examined the status quo of how well they are addressed. Then, we derived a set of requirements for addressing or relieving the identified problems and issues. A good understanding of PV problems and domains may effectively contribute to the theory building of this research.

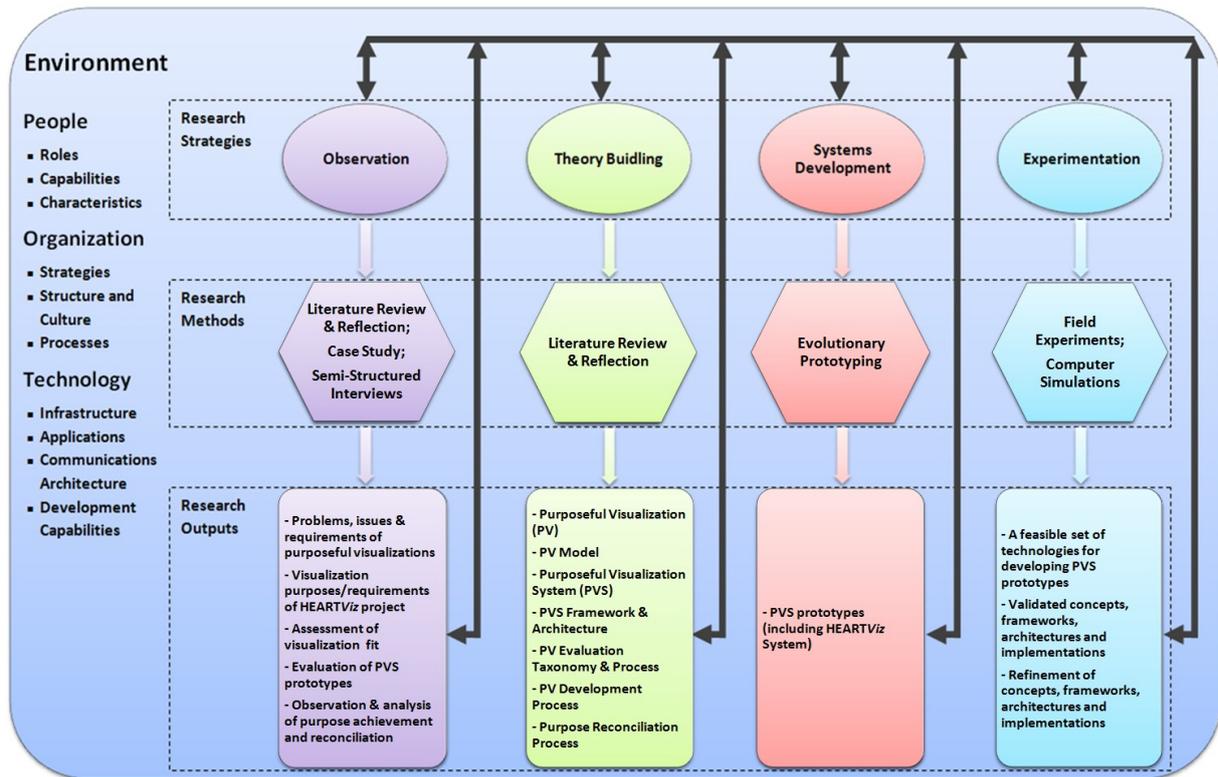


Figure 3. An instantiated multi-methodological research framework

Theory Building

The theory building strategy is applied for developing new concepts, models, processes, frameworks and architectures. To realize this research strategy, we review the extant literature about purposeful visualizations and ensure that our proposed artefacts incorporate the good practice of modeling and scenario planning, effective visualization design patterns, and etc. The main research outputs of this strategy are formal definitions of PV and PVS, PV model, PVS system frameworks and architectures, and PV development and evaluation processes.

Systems Development

The systems development strategy is used to validate the proposed theories and system designs, and the experience gained through prototype development can also help with refining the proposed theories frameworks and architectures. This strategy is implemented through applying evolutionary prototyping to guide the design and development of prototypical systems. Evolutionary prototyping generally starts with implementing confirmed and well-understood system requirements. Then, it continuously refines and adds more functionality to the prototype based on the user feedback collected and the deeper understanding of the system requirements until user expectations are matched (Davis, 1992; McConnell, 1996). Evolutionary prototyping is selected due to its widely acknowledged advantages. This system development approach is particularly useful to deepen the understating of system requirements and identify missing requirements (Davis, 1992; Lichter, Schneider-Hufschmidt & Zullighoven, 1994). It also minimizes the risks and uncertainties associated with a system development process and attempts to address them at earlier stages (Connell & Shafer, 1995; McConnell, 1996; Carter, Anton, Dagnino & Williams, 2001). Furthermore, it facilitates establishing regular communications between system developers and end users and hence achieving better opportunities to deliver system prototypes with good quality and user satisfaction (Connell & Shafer, 1995).

Experimentation

The experimentation strategy is deployed to aid in validating and refining our proposed concepts, models, processes, frameworks, architectures and prototypes. This strategy is realized by computer simulations and field experiments. Computer simulations are adopted to help us identify appropriate computer technologies to develop prototypical systems. The prototypes are then applied to different problem domains to generate visualizations, which are further evaluated via field experiments in terms of the support for achieving their intended purposes. Field experiments, which are tightly coupled with observation, aim to facilitate collecting user feedback on the visualizations. The feedback collected may in turn assist us with refining our proposed theories and system implementations.

5 CONCLUSION

Information systems (IS) research is complex in nature. Such complexities are caused by the diversity of IS research areas, interests and artefacts, the various dimensions of problem situations and materials and the dynamic social and personal research contexts. The complexities involved tend to require the adoption of appropriate multi-methodological approaches to provide theoretical and practical guidelines for conducting IS research. However, integrating and mapping multiple research methodologies is not an easy task to accomplish. By examining and synthesizing representative multi-methodological research approaches, we realize that each multi-methodological research framework has its own strengths and weaknesses. Therefore, we take Nunamaker et al.'s (1991) system development oriented research framework as our starting point, integrate the strengths of other representative research approaches to remedy the deficiencies of Nunamaker et al.'s (1991) framework, and then introduce the integrated multi-methodological research framework. To demonstrate its usage, we instantiate and apply it to a research project in the domain of information visualization, and discuss how the instantiated research framework helps to achieve various research objectives. It deserves to be pointed out that the proposed integrated research approach has only been tested within a very limited number of IS research projects. The application of the integrated framework in a variety of studies ranging from business to art to history to engineering to science will be accomplished in our future research.

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