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Design science research on systems analysis and design: The case of UML

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Citation

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Abstract

Design science in the IS discipline seeks to create artifacts that embody the ideas, practices, technical capabilities, and products required to efficiently accomplish the analysis, design, implementation, and use of information systems (Hevner et al 2006). SA&D research, being close to the design science paradigm, has suffered from a lack of appreciation from the behavioral science paradigm. To provide a paradigmatic foundation, we propose a conceptual framework for SA&D research. The framework was developed based on several essays that systematically articulate the design science paradigm in the IS field. Using this framework, we reviewed some UML papers that appeared in the proceedings of AMCIS. This preliminary literature analysis indicates that our framework for SA&D research is viable and does manifest itself in the IS literature.

Keywords: Design Science, Systems Analysis and Design, UML

Introduction

Systems analysis and design (SA&D) is arguably one of the core areas in the information systems (IS) discipline. In practice, SA&D seeks to identify business problems, capture information requirements, analyze data structure, and design computerized information systems. It is regarded as a composition of the critical activities that determine, to a great extent, the success of any information systems development project. In research, SA&D researchers aim to identify and solve problems that arise during the analysis and design activities (Iivari et al. 2006). Here, we focus on the science-dimension of SA&D, i.e. SA&D research.

Whereas many of the IS courses we teach focus on design and developing information systems, research in design-related issues is scattered and under represented in IS literature. Many factors may have contributed to this teaching-research gap (Bajaj et al. 2005), such as lack of exposure in top IS journals, lack of understanding and appreciation within institutional settings, inadequate training of doctoral students, and allegation of insufficient research rigor. All these factors, however, can be traced to the paradigm difference between SA&D research and other IS studies. Research paradigm in this context refers to the substance of "what is being studied." Hevner et al. (2004) identified two paradigms that characterize much of the research in the IS discipline: behavioral science and design science. The behavioral-science paradigm, which stems from natural science research methods, seeks to *find* "what is true." In contrast, the design-science paradigm, which "has its roots in engineering and the sciences of the artificial (Simon 1996)" (p.76), seeks to *create* "what is effective."

SA&D research is essentially in the domain of the design science paradigm. The primary objective of SA&D research is to create and/or evaluate IT artifacts that are intended to solve identified organizational problems in the analysis and design of information systems. According to March and Smith (1995), the IT artifacts that are produced by design-science research in IS broadly include constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented and prototype systems). In the area of SA&D, considerable research effort has focused on constructs, such as the Entity-Relationship Model (ERM) (Chen 1976) and the Unified Modeling Language (UML), and methods for applying these constructs to create information models.

Since much of the published IS research employs the behavioral science paradigm to develop and verify theories that explain or predict human and organizational behavior, IS researchers have extensive exposure to issues related to the behavioral science, such as theoretical foundations, research methods, and evaluations. Some researchers have made efforts to introduce the less known design science paradigm to the IS community as being complementary to the behavioral science paradigm in IS research (Gregor 2006, Hevner et al. 2004, Iivari 2002, Walls et al, 1992). No study, to our best knowledge,

has extensively discussed SA&D research from the design science perspective. SA&D research is frequently closer to design science than to IS mainstream behavioral science (Bajaj et al, 2005). Thus, a survey of design science research on SA&D is necessary to assess the state of the research, to obtain a better understanding, and to promote more high-quality studies in this important area of research.

Many challenging issues in SA&D wait to be investigated, such as modeling, object oriented development, agile methods, and distributed development environments (Bajaj et al. 2005). In this study, we examine prior research investigating issues related to UML as special cases of SA&D research. The primary goal of this paper is to achieve a deeper understanding of and appreciation for the design science paradigm in SA&D research. A review of UML studies is appropriate for this purpose due to: 1) UML represents not only the constructs but also the methods for information modeling, a central topic within SA&D; 2) UML, an industry standard for object-oriented modeling, has been in existence for 10 years and generated considerable research interests in SA&D community; 3) the pervasive adoption of UML reflects the overall transition to object oriented development in industry. This study, therefore, not only addresses the issue of design research as a research imperative (Hevner et al 2004, Iivari 2002, March and Smith 1995, Walls et al 1992) but also answers the call for relevance of IS research to IS practitioners (Benbasat and Zmud 1999, Iivari et al 2004).

The rest of the paper is organized as follows. In the theoretical background section, we introduce concepts associated with research paradigms and describe the boundaries of SA&D research within the design science paradigm. We do so by developing a conceptual framework for understanding SA&D research from the design science perspective. Next, we review the guidelines for conducting and evaluating good design science research (Hevner et al 2004) and discuss their applicability in SA&D research. Based on the proposed framework and clarified guidelines, we assess recent exemplar papers on UML in the IS literature. Finally, we discuss the study's implications and future research directions.

Theoretical Background

In this section, we first introduce the concepts related to the design science paradigm in IS research. Then, we describe the major issues in SA&D research, and how they are linked to the design science paradigm. In the end, we propose a conceptual framework for understanding SA&D research from the design science perspective.

Design science paradigm in IS research

In the IS literature, questions relating to "what is being studied" have been raised frequently in response to the pursuit of theoretical core and academic identity of the information systems field. Despite its importance, discussions on this topic are limited in comparison with discussions on epistemology, i.e. "way of knowing" such as positivism and interpretivism. Some researchers have hinted at the paradigm differences among IS research efforts. For example, Walls et al. (1992) articulated the distinctive features of design theory in IS research, and pointed out that the purpose of the social science theory is to explain why specific goals exist or predict outcomes associated with goals; in contrast, the purpose of a design theory is to support the achievement of goals. Not until recently have some IS researchers made a systematic effort toward clarifying the paradigm differences in IS research.

Hevner et al's seminal essay (2004) on design science in IS research proposes to make the role and value of design science IS research more visible. They identified two complementary but distinct paradigms in IS research: the behavioral science paradigm seeks to develop hypotheses and empirically justify theories that explain or predict organizational and human phenomena surrounding the analysis, design, implementation, and use of information systems; the design science paradigm seeks to create innovations, or artifacts, that embody the ideas, practices, technical capabilities, and products required to efficiently accomplish the analysis, design, implementation, and use of information systems. In proposing a conceptual framework for understanding IS research, Hevner et al (2004) further pointed out that the goal of behavioral science research is truth, while the goal of design science research is utility. Truth and utility are inseparable in that "truth informs design and utility informs theory". In other words, "an artifact may have utility because of some as yet undiscovered truth. A theory may be yet to be developed to the point where its truth can be incorporated into design" (p.80).

Based on the information systems research framework, Hevner et al (2004) provided an in-depth articulation of the essence of design science. They claimed that "design science research addresses important unsolved problems in unique or innovative ways or solved problems in more effective or efficient way" (p.81). They recognized the artificial nature of organizations and the information systems that support them, and rooted their argument in the sciences of the artificial (Simon 1996). Hevner et al (2004) also developed a set of guidelines for conducting and evaluating good design science research. They used the proposed guidelines to assess some exemplar papers in order to illuminate how to apply them consistently in research, review, and editorial activities. Hevner et al (2004) concluded that the design science paradigm "can play a significant role in resolving the fundamental dilemmas that have plagued IS research: rigor, relevance, discipline boundaries, behavior, and technology."

Hevner et al's (2004) view on design science paradigm has been echoed, to different extent, in recent IS literature. For instance, Iivari (2002) pointed out the lack of constructive research in the IS literature and argued for an applied, engineering-like discipline that develops various meta-artifacts to support the development of information systems. In a

recent research essay that examines the structural nature of theory in IS, Gregor (2006) classified *theory for design and action* as one of the five major types of theory in the IS literature. The primary goal of such theories is prescription, i.e. a description of the method or structure or both for the construction of an artifact.

The design science paradigm provides an effective foundation on which SA&D studies can be conducted and evaluated. This is because SA&D research, by it nature, is closer to design science as opposed to behavioral science (Bajaj et al 2005). Before we further elaborate on the ties between SA&D research and design science paradigm, we would like to review the major issues within SA&D.

Research questions in SA&D

SA&D refers to a number of activities in information systems development, typically carried out in the early stages. The main purpose of systems *analysis* is to identify and document the requirements for an information system to support organizational activities. In contrast, systems *design* aims to define the system architecture, components, modules, interfaces, and data storage for a software system to satisfy the requirements specified during systems analysis (Iivari et al 2005). There are several primary activities in SA&D.

Information Requirements Determination

It has been recognized that determining correct and complete information requirements is a vital part of designing an information system. As a matter of fact, many IS failures can be attributed to a lack of clear and specific information requirements. Information requirements determination, also known as requirements definition, requirements gathering, requirements elicitation, and requirements engineering, is concerned about figuring out what to build. It involves a set of activities used by systems analysts to assess the functionality required in a proposed system. Four tasks to be performed in requirements determination have been identified Pohl 1996):

> ➢ Requirements specification: to understand the organizational situation that the system under consideration aims to improve and describe the needs and constraints of the system under development

> ➢ Requirements negotiation: to establish an agreement on the requirements of the system among the various stakeholders involved in the process

> ➢ Requirements representation: to develop a mapping of real-world needs onto a requirements model.

> ➢ Requirements validation: to ensure that the derived specification corresponds to the original stakeholder needs and conforms to the internal and/or external constraints set by the enterprise and its environment.

Conceptual Modeling

Conceptual modeling is the cornerstone of information requirements determination. Information models, the products of conceptual modeling, not only provide the required representations to facilitate communication among stakeholders, but they also provide a formal basis for developing information systems. In particular, conceptual modeling is directly related to two tasks in requirements engineering – requirements representation and requirements validation. In requirements representation, conceptual models are created to map real-world needs. During requirements validation, stakeholders verify whether their needs have been correctly specified by looking at the generated conceptual models.

Data Modeling

Most information systems are data-centric. To effectively manage and organize data in computerized information systems, system analysts often conduct data modeling activities during SA&D. Data modeling is the process of creating data models which represent, often visually, the organization and structure of data. Entity-Relationship (ER) modeling (Chen 1976) is one of the most popular types of data modeling techniques. It was designed in late 1970s as a method for modeling data structures at the conceptual level.

A great number of system development failures can be attributed to problems that arise during systems analysis and design. Therefore, understanding and improving systems analysis and design are central to the research mission of the IS discipline (Bajaj et al 2005, Iivari et al 2006). SA&D practitioners and researchers usually design various artifacts to improve the efficiency and effectiveness of SA&D activities, and ultimately the usefulness of the resulting system. The artifacts can range from modeling symbols and methods, to requirements elicitation techniques, and to Computer-Aided Software Engineering (CASE) tools. Despite its significance, SA&D research is under represented in the IS literature (Vessey et al 2002). We concur with Hevner et al (2004) that behavioral science and design science compose a complete research cycle to address fundamental problems faced in the productive application of information technology. Nonetheless, we attribute the scarcity of SA&D publications to the likely over-emphasis of SA&D research on behavioral science paradigm. Therefore, a deeper understanding about how SA&D research fits in the domain of design science will help resolve the issue of "comparing apples to oranges."

A Framework for SA&D research

Before proposing a framework for SA&D research, we first clarify some related terms. First, confusions may arise about the meaning of behavioral science and other similar terms such as social science, organizational science. Here we adopt a taxonomy developed in van Aken (2004), which distinguishes three categories of scientific disciplines: (1) the formal sciences; (2) the explanatory sciences; and (3) the design sciences. The mission of formal sciences, such as philosophy and mathematics, "is to build systems propositions whose main test is their internal logical consistency" (p.224). Explanatory sciences, including natural sciences and major sections of the social sciences, seek to describe, explain and possibly predict observable phenomena within their own field. The objective of design sciences is "to develop knowledge for the design and realization of artifacts, i.e. to solve construction problems, or to be used in the improvement of the performance of existing entities, i.e. to solve improvement problems." From this taxonomy, it is clear that either "behavioral science" as used in Hevner et al (2004) or "social science" as used in Walls et al (1992) belongs to the domain of explanatory sciences with an emphasis on *finding* "what is true." On the other hand, design sciences stress on *creating* "what is effective" (Hevner et al 2004)

Second, there are different interpretations regarding the term "artifact." For instance, Orlikowski and Iacono (2001) articulated multiple definitions of the term IT artifact, many of which include components of the organization and people involved in the use of a computer-based artifact. In this context IT artifact is equivalent to the concept of information systems that are built for specific business purposes. March and Smith (1995) identified four types of artifacts produced by design science research in IS: constructs, models, methods, and instantiations. Hevner et al (2004) further clarified the definition of the artifact: 1) constructs provide the vocabulary and symbols used to define problems and solutions; 2) constructs enable the construction of models or representations of the problem domain 3) methods are followed to build models using constructs; 4) instantiation demonstrates feasibility both of the design process and of the designed product. In the context of SA&D, an example of *construct* artifact can be UML, which is standard vocabulary for object-oriented modeling. The diagrams created following UML specifications, such as class diagrams and use case diagrams, can be regarded as the *model* artifacts of the problem domain. A text that introduces the ways of using UML to model business problem and system requirements is an example of *method* artifact. Finally, a CASE tool that supports UML modeling activities can be considered as an *instantiation* artifact.

The result of design science research in IS is a purposeful artifact that is created to address an important organizational problem (Hevner et al 2004). In SA&D research, the creation and evaluation of a design artifact are key issues to be judged (Bajaj et al 2005). With this understanding, we propose a conceptual framework (see Figure 1) for understanding SA&D research from the design science perspective.
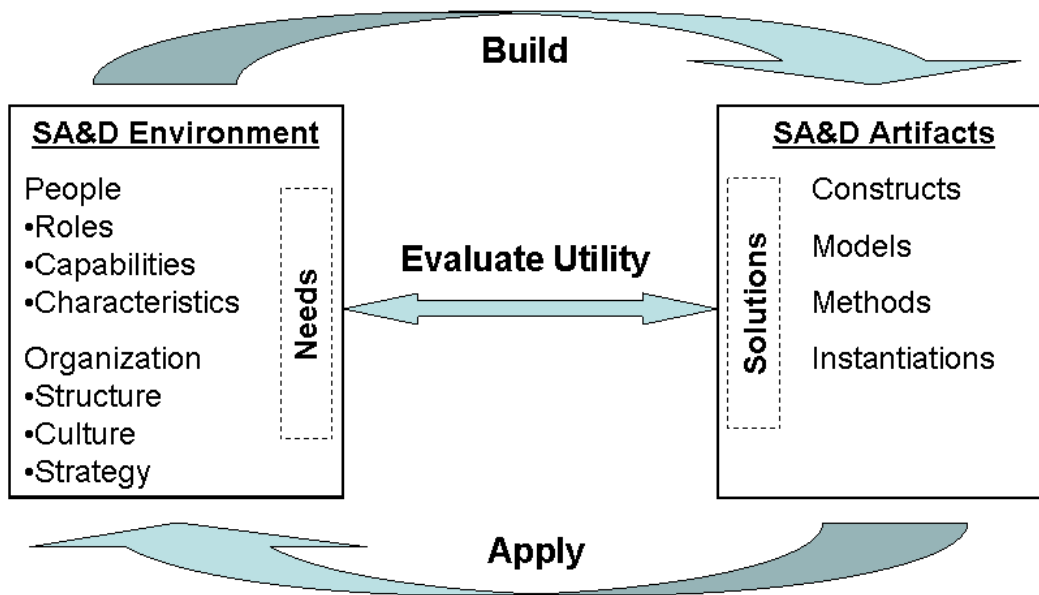
Figure 1: Framework for Systems Analysis and Design Research

The SA&D environment defines the problem space (Simon 1996) in which reside the people and organizations involved in SA&D activities. People include, but are not limited to, system analysts, developers, users, project sponsors, project managers. Their perceptions regarding SA&D needs are shaped by their roles, capabilities, and characteristics. SA&D needs are also assessed within the organization's structure, culture, and strategy. Together these define the "problem" as perceived by the SA&D researcher. Facing specific needs, SA&D research is conducted in two possible ways. On one hand, researchers and practitioners may *build* innovative and new SA&D artifacts to meet the identified needs. On the other hand, researchers and practitioners may *apply* existing SA&D artifacts to address the specific needs. As utility is the ultimate objective of design science, SA&D artifacts in either case must be evaluated with respect to the utility provided in meeting the needs.

One issue that must be addressed in design science research is differentiating routine design from design research (Hevner et al 2004). In the context of SA&D, we need to differentiate SA&D practice from SA&D research. SA&D practice is the application of existing artifacts to routine SA&D problems, such as modeling users' information requirements using UML's use case diagram for a payroll system. On the other hand, SA&D research addresses either important unsolved problems in unique or innovative ways, or significant solved problems in more effective or efficient ways. The key differentiator between SA&D practice and SA&D research is the clear evaluation of utility. In other words, SA&D artifacts (constructs, models, methods, and instantiations) under scrutiny must be subject to an evaluation of utility provided in

meeting the business needs, either in a build-oriented research or in an apply-oriented research. It is possible that an SA&D study purely assesses the utility of a particular artifact to certain business needs.

Guidelines for SA&D Research

The conceptual framework presented above provides a paradigmatic foundation on which SA&D research can be conducted. In this section, we discuss the guidelines for SA&D research following the design science paradigm.

Hevner et al (2004) derived seven guidelines from the fundamental principle of design science research, which "is that knowledge and understanding of a design problem and its solution are acquired in the building and application of an artifact. That is, design-science research requires the creation of an innovative, purposeful artifact (Guideline 1) for a specified problem domain (Guideline 2). Because the artifact is purposeful, it must yield utility for the specified problem. Hence, thorough evaluation of the artifact is crucial (Guideline 3). Novelty is similarly crucial since the artifact must be innovative, solving a heretofore unsolved problem or solving a known problem in a more effective or efficient manner (Guideline 4). In this way, design-science research is differentiated from the practice of design. The artifact itself must be rigorously defined, formally represented, coherent, and internally consistent (Guideline 5). The process by which it is created, and often the artifact itself, incorporates or enables a search process whereby a problem space is constructed and a mechanism posed or enacted to find an effective solution (Guideline 6). Finally, the results of the design-science research must be communicated effectively (Guideline 7) both to a technical audience (researchers who will extend them and practitioners who will implement them) and to a managerial audience (researchers who will study them in context and practitioners who will decide if they should be implemented within their organizations)" (p.82).

These general guidelines are proposed to assist researchers, reviewers, editors, and readers to understand the requirements for good design science research. There are also applicable to SA&D research. Here we would like to discuss the links of these guidelines to our conceptual model.

First, SA&D research must involve an SA&D artifact in the form of a construct, a model, a method, or an instantiation, as shown in the right textbox in Figure 1. This corresponds to Guideline 1 in Hevner et al (2004) – design as an artifact.

Second, SA&D research must address important and relevant business needs, as shown in the left textbox in Figure 1. This is related to Guideline 2 in Hevner et al (2004) – problem relevance.

Third, an SA&D artifact must be evaluated with respect to the utility provided in meeting the needs, as shown in the horizontal arrows in Figure 1. This is akin to Guideline 3 in Hevner et al (2004) – design evaluation.

The remaining four guidelines are related to the ways of conducting SA&D research and presenting results. The objectives include improve research rigor, provide clear and verifiable contributions, utilize available means to research desired ends, and present findings effectively to the potential audience.

UML Studies as Design Science Research

UML is an industry standard for object-oriented modeling. Since its inception in late 1990s, UML has been widely adopted and used by the IS development community. During the same period, IS researchers conducted many studies related to the design, adoption, use, and enhancement of UML. In this section, we examine some exemplar UML studies using the framework developed above.

As a preliminarily "proof of concept" test that our framework for SA&D research is viable and does in fact manifest itself in the IS research literature, we conducted a literature analysis of UML research articles appeared in the proceedings of Americas Conference on Information Systems (AMCIS). In a 12-year history of AMCIS so far (1995-2006), a total of 16 articles have been addressing research questions related to UML. The small number of UML-related publications in AMCIS proceedings is surprising, given the fact that UML was initially accepted by Object Management Group (OMG) in 1997 as the standard modeling language and has since then been extensively adopted in industry (Dobing and Parsons 2006).

Of the sixteen articles, two of them are explicitly within the domain of behavioral science. Grossman et al (2004) investigated the adoption and use of UML in the software development community. Using task-technology fit instruments, they administered a survey and found a wide diversity of opinions regarding UML's use and effectiveness. In a research-in-progress (Siau and Tan 2005), the researchers developed a research model, which describes the relationships among performance disconfirmation, effort disconfirmation, satisfaction, perceived usefulness, perceived ease of use, attitude, and continuance intention. The model was deductively developed to understand the continued use of UML by IS developers.

We conducted a literature analysis of the rest fourteen UML papers based on the framework of SA&D research. We reviewed each paper and tried to identify the key components, if any, of SA&D research and research focus of every study. The results are shown in Table 1.

Table 1: Analysis of UML studies using the framework of SA&D research

Study	Key components in SA&D research			Research focus (build, apply, or pure evaluation?)
	Needs (SA&D problem)	Solutions (SA&D artifact)	Evaluation (Utility)	
Jackson 1998	Document user requirements	Method: ways of creating UML diagrams	N/A	Apply
Araujo and Moreira 2000	Improve precision of the specification	Method: ways of using Object-Z to specify UML collaborations	Demonstrated through a case	Build
Wang 2001	N/A	Construct: UML	N/A	Pure evaluation
Marchewka and Liu 2001	Improve communication and understanding for XML developers and users	Construct: UML	Demonstrated through an example	Apply
Siau and Shen 2002	Novice analysts' learning problem	Construct: UML	N/A: research in progress	Pure evaluation
Sugumaran et al 2002	Develop better systems for financial statement analysis	Method: a framework to couple the strengths of UML and XBRL	N/A	Build
Erickson and Siau 2003	UML's cognitive complexity to users and analysts	Construct: UML	N/A: research in progress	Pure evaluation
Seng 2004	Transform between XML and UML	Method: production rules for transformation	N/A	Build
Cao 2004	Measure the efficiency of OOSAD process	Method: approach to use UML complexity metrics	Demonstrate through a preliminary study	Build
Erickson and Siau 2004	UML's cognitive complexity to users and analysts	Construct: UML	Demonstrate through a preliminary study	Pure evaluation
Mrdalj Jovanovic 2005	Describe enterprise architecture	Method: ways of mapping UML to Zachman framework	N/A	Build
Siau and Tian 2005	UML's complexity to analysts	Construct: UML	Evaluation based on semiotics	Pure evaluation
Callaghan et al 2006	Developing management appraisal system	Method: ways of using UML to map XBRL applications	Demonstrate through examples	Build
Bolloju 2006	Training novice system analyst	Model: UML diagrams	Evaluation based on conceptual model quality	Apply

The literature analysis of the fourteen papers indicates that there is a mixture of research focuses. Three studies are aimed at apply existing SA&D artifacts that are related to UML to meet particular needs. Six papers report build-oriented research that designs new SA&D artifacts to meet identified needs. Five papers target at pure evaluation of certain aspect of utility. In the following section, we discuss, in detail, how the framework of SA&D research can help better understand these UML studies from the design science perspective.

Discussion

The paucity of UML research, which is apparent as compared to the sheer number of total articles published in AMCIS proceedings, partially reflects the fact that SA&D research is under represented. As we pointed out above, the issue may be attributed to the lack of paradigmatic foundation for SA&D research, particularly UML studies in this case. SA&D research is closer to design science than to behavioral science. Thus, reviewers and editors cannot always use the guidelines for conducting behavioral science studies to evaluate SA&D studies. We earlier proposed a framework to facilitate an understanding about the design science nature of SA&D study.

Three key components are identified: needs, solution, and evaluation of utility. According to our literature analysis of the fourteen SA&D studies that are related to UML, we found that all of them address needs (domain problem) and solutions (SA&D artifact) to different degrees. Some studies (e.g., Callaghan et al 2006, Siau and Tian 2005) express the domain problem explicitly, while some others implicitly mention the business needs. In terms of evaluating utility, some studies do not evaluate and justify the utility of SA&D artifacts in solving the business problems. Araujo and Moreira (2000) used a case study to demonstrate the utility of their proposed ways of using object-Z to specify behaviors of UML collaboration. In another study, Callaghan et al (2006) discussed the utility of their method for using UML to map XBRL applications through several examples. Overall, the level of utility evaluation and justification is low across the studies we reviewed. This may be due to the limited space for conference proceedings or the status of study being research-in-progress. This may also be attributed to the lack of awareness among these researchers about the need for utility evaluation.

Hevner et al (2004) suggested some guidelines to ensure and improve the contributions of design science research, one being research rigor, and another being research presentation. From our review, we found the lack of rigorous methods in both the building/application and evaluation of the SA&D artifacts. This issue can be solved through systematic articulation of rigorous methods in design science research. In other words, design science researchers need to be aware of common methods for building/application and evaluation of the SA&D artifacts, similarly to their counterparts in behavioral sciences learning various research methods.

The presentation styles of the papers we reviewed are diverse. It is apparent that some researchers have tried hard to present their studies following behavioral science norms. Some other researchers, on the other hand, took the technical approach in presenting their research. The lack of a commonly acceptable format of presentation for design science research, in particular SA&D research will make it hard to convey findings to reviewers and readers. This problem needs to be solved in order to build the knowledge base in SA&D research.

Conclusion

Design science in the IS discipline seeks to create artifacts that embody the ideas, practices, technical capabilities, and products required to efficiently accomplish the analysis, design, implementation, and use of information systems (Hevner et al 2006). SA&D research, being close to the design science paradigm, has suffered from a lack of appreciation from the behavioral science paradigm. To provide a paradigmatic foundation, we propose a conceptual framework for SA&D research. The framework was developed based on several essays that systematically articulate the design science paradigm in the IS field. Using this framework, we reviewed some UML papers that appeared in prior year proceedings of AMCIS. This preliminary literature analysis indicates that our framework for SA&D research is viable and does manifest itself in the IS literature.

We concur with Hevner et al (2004) that both the behavioral science paradigm and the design science paradigm are foundational to the IS discipline. Being able to appreciate the studies from other paradigms will greatly benefit the field, which is positioned at the confluence of people, organizations, and technology (Silver et al 1995). Our paper represents an effort to enhance the understanding of SA&D research from the design science perspective. With the proposed framework, SA&D researchers can conduct their research more effectively. The proposed framework also informs other IS researchers regarding appropriate ways to evaluate and appreciate SA&D research.

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