December 2006

Designing over the Horizon: Architecting for Emergence

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ABSTRACT

This work links architecture to such organizational outcomes as IT flexibility and business value. I connect changes in architecture with technological and market uncertainty, I show how investments in architecture create real-option value, and I describe how firms manage their architecture by developing an architectural capability.

In this work I develop software tools that enable architects to assess, manage, and appreciate the impact of the gap between espoused and emergent architecture. The tools enable organizations to evaluate investments in architecture and automate the mapping of their architecture by probing the network and attached operating systems.

Keywords

Architecture, design science, emergence, complexity, adaptation, enterprise architecture.

INTRODUCTION

As system developers interact with stakeholders they build systems that interconnect software components (Hopkins 2000). The resulting collection of systems constitutes the organization's information system. The information system, however, is more than the sum of its components. At runtime the components of the system communicate with each other through various mechanisms. The pattern of this communication results in, and is a consequence of, interdependencies that can be described as the information systems architecture (i.e., the enterprise architecture) (Kayworth, Chatterjee and Sambamurthy 2001; Perry and Wolf 1992). Architecture does not require a designer (an architect) (Alexander 1964; Simon 1996 [1969]), but there is a long stream of research that suggests such design efforts are productive (Brooks 1975).

The architect can design an architecture (the espoused view). However, implementation of systems over time often results in an emergent architecture that is different from the espoused view (Iyer and Gottlieb 2004). Inevitably, there is a gap that forms between the espoused and emergent views which results in a gap between the expected and realized value of the information system. This gap may be positive or negative. The designer could attempt to minimize this gap or take advantage of this gap; however, it should not be ignored.

A firm may invest in creating an architecture (i.e., the espoused view). However, the emergent architecture is what is implemented and it influences system flexibility (Duncan 1995), cost predictability, value creation (Henderson and Venkatraman 1993), and architectural control. Architectures, like all designs, are expensive to create, are the result of uncertain processes, and create real-options on future decisions (Amram and Kulatilaka 1999; Baldwin and Clark 2005). Organizations can decide if and when they need to invest in the architecture of their information systems (IS). In some cases, it may be perfectly reasonable for an organization to focus on components and not on how they interconnect (if they interconnect at all). Organizations can invest in architectural design, component design, or a combination of the two (Brooks 1975). In order for organizations to make appropriate architectural decisions, including the decision regarding when to invest in architecture, they need a dynamic capability (Teece, Pisano and Shuen 1997) – architectural capability. This capability enables organizations to manage the changing interdependencies between systems.

The interdependencies that make up the architecture directly influence the cost of modifying the system and the ease of realizing its value (Baldwin and Clark 2000). I theorize that the costs are driven by the following factors: 1) complexity – the more interacting variables, the greater the number of unanticipated interactions, and the greater the cost in identifying and managing them (Simon 1996 [1969]) and 2) constraint – the greater number of dependencies the less flexible a system can be, thus increasing the cost in responding to new opportunities (Kayworth et al. 2001; Perry et al. 1992).

The core of my research is to develop a conceptual model for architectural decision making, to support this model with an architectural investment decision support tool, and validate this tool at a research site that I've identified. This project incorporates a number of important subcomponents. First, I will develop a tool and set of methods to automate the capture and rendition of the runtime view of the information system. Second, I will validate the rendition by comparing it to the recollection of the system architects. Third, I will validate the importance of the decision support tool by correlating features within the architecture (i.e., varying degrees of interdependency) with perceived and actual performance measures (e.g., flexibility, value, cost predictability). Fourth, I will explore, through structured interviews (Yin 1994), the antecedents of specific topological features within the architecture and connect these antecedents with technological and market uncertainty and the search for value (Baldwin et al. 2000; Clark 1985; Hirshleifer 1973). Fifth, through the same set of interviews I will identify dimensions of architectural capability, the antecedents of the gap between the espoused and emergent architecture, and the loss of control that emergence may imply.

This research will be conducted following the general methodology and precepts of design science (Hevner, March, Park and Ram 2004). The decision support and data capture tools are motivated by extant organizational and design theory research. I expect to contribute to improved organizational understanding, improved decision making processes, and a richer understanding of architecture. The utility of the tools will be established through the theories they help test.

The remainder of this paper is organized as follows. In the next section I present an overview of some of the key theories that I will be using and augmenting and some of the hypotheses I will test. In the subsequent sections I will describe the research setting, the measures I will collect from the setting, how I will operationalize the measures, the methods I will use to test the hypotheses, and the results I expect. I will then conclude and describe limitations and future work.

THEORY AND HYPOTHESES

Complexity

Organizations search for value in a complex, rugged solution space (Levinthal 1997; Rivkin and Siggelkow 2003; Simon 1996 [1969]). Given enough time, they could eventually discover an optimal or satisficing point (Simon 1997 [1945]). Organizations build information systems to support this search (Henderson et al. 1993; Kayworth et al. 2001) and we have every reason to believe that the optimal or satisficing architecture would also be found. However, in a dynamic world the important design constraints and critical subsystems change over time, resulting in patterns of disruptive change in economies, firms, and products (Henderson and Clark 1990). As a result, firms go through a process of sequential search in product design, organization, and routines, adjusting their internal processes to a changing external environment (Nelson and Winter 1982; Simon 1996 [1969]). Such an evolutionary, emergent process modifies the pattern of interdependencies I've previously described by adding new interdependencies, but often without eliminating preceding ones as the "installed-based" is supported (Bresnahan and Greenstein 1999).

H1a: Environmental change increases architectural complexity.

H1b: Internal reductions in the cost of interdependency increases architectural complexity.

Design

The increasing complexity described above results in increasing costs as the number of unanticipated interactions between interdependent components increases. In order to manage this increasing complexity, firms can re-architect their systems into more modular subcomponents (Baldwin et al. 2000; Simon 1996 [1969]). Such design activities can create substantial value but can also involve substantial costs.

Although one can suggest designing is an ongoing process in software system development, in this work I define designing as that part of the system creation process that does not involve writing (or the automatic creation of) lines of code. Implementation activities are the balance of the activities required to bring a design to fruition. When should the explicit process of designing be employed, and how should one balance short and long-term designing? Firms ask these questions in information environments that are at times uncertain and/or ambiguous (Daft, Lengel and Trevino 1987). The answers to these questions will influence contingent, future design decisions (Amram et al. 1999).

Each design represents a portfolio of solutions in that search space consisting of the design plus a portfolio of contingent decisions. Thus, we can say that a design is a portfolio of real-options (Baldwin et al. 2000). The design activity provides a (boundedly) rational search through the design space. Design decisions are made based upon the current knowledge, intuition, and assumptions of the design team regarding the designed system and its context. Certain decisions are informed by best practices and require little judgment; other decisions require the expert evaluation by the design team. In effect, the design team eliminates design options that have little expected future options value while minimizing its own investment in doing so.

Thus, the design activity minimizes the design search space that must be explored through implementation activity. However, there is an inherent limit to the value of design activity in the absence of instantiation activity. It is only through instantiation that some of the interaction effects can be observed, technological uncertainties can be reduced, and market uncertainties resolved. Therefore, system developers need to balance design and implementation activity.

Design can be oriented along two dimensions: components and systems. Systems design (architecture) defines what happens and how the components interact; component design (implementation) defines how it happens. Architecture (systems design) provides the description of the external interface that the user-community interacts with. Implementation is no less creative. Implementation focuses on how each component does its job in the most efficient way possible (Brooks 1975). Organizations navigate the investment trade-offs implicit in these dimensions through their architectural capability.

Following Brooks' distinction, I argue that designing for options value, the province of architecture, is distinct from designing for efficiency, the province of implementation. Also following Brooks, I argue that both are important in predicting system success. If we use the language of complexity and design (Baldwin et al. 2000; Simon 1996 [1969]), designing for options is concerned with creating the near decomposability, the right level of modularity, and the right dependencies between the modules. By contrast, designing for implementation is concerned with the structure of the components and the dependencies within a component.

H2: Increasing design complexity is associated with reduced system flexibility.

Architecture

In order to evaluate when to engage in architectural investment, to determine the extent of that investment, and to properly make architectural decisions, it can prove useful to have a rendition of the current architecture. There are many views of architecture (Iyer et al. 2004; Kayworth et al. 2001; Perry et al. 1992; West and Dedrick 2000; Zachman 1999 [1987]). From a dynamic perspective there are three views of architecture that are potentially interesting in this research – the espoused (the design), the emergent (what's in production), and the in-use view (Iyer et al. 2004). While acknowledging the ensemble, in-use view (Orlikowski and Iacono 2001), I am taking the position that the provenance of the architect is limited to the software systems themselves and that the architect must be concerned with the architecture as it is, and not how he or she originally designed it or imagines it to be. In order to capture the architecture as it has emerged over time, it may be valuable to have an automated solution that interrogates the information system at run-time rather than identifying and querying the knowledge of distributed IS decision makers whose knowledge of the system or particular components may be incomplete.

H3: There will be a difference between the architecture as perceived and the architecture as captured.

H4: Emergence in architecture results in a loss of architectural control or a change in architectural focus.

H5: Architectural capability is associated with adaptation to technological or market change.

Architecting

The search for valuable designs can be described through the modularity operators (Baldwin et al. 2000). As a result of new business initiatives, the architecture is augmented and existing modules are integrated. This increases value for the business at the cost of increased complexity in the architecture. The increased complexity leads to increased costs for the next project. As a result, the threshold to justify a new project increases and fewer projects are implemented. The information gathered from implementation activity, however, may lead to insights that enable re-architecting projects. These projects primary purpose may be to reduce complexity, and thus reduce the cost of future business initiatives. Thus, the process of architecting is part of the cyclic dance that creates organizational knowledge (Nonaka 1994).

H6: Investments in architecture are associated with increased system flexibility and increased long-term value in conditions of high technological and/or market uncertainty.

H7: Investments in architecture lead to greater uncertainty in project outcome and higher expected value.

H8: Investments in architecture lower the cost of business initiatives.

SETTING

In order to explore our questions in an empirical setting, I have gained access to a biopharmaceutical firm in which I can collect spending and performance data on various design and implementation activities across multiple projects. The company has 190 systems and is currently engaged in an IS re-architecting project.

MEASURES

This work involves the creation of three software systems. First, I will create an architectural investment decision support tool in which architectural investments and project implementations are simulated under varying conditions of technological, market, and financial uncertainty. Both the long-term and short-term consequences of architectural investment can be evaluated under varying conditions. Second, I will design a database and associated data-entry tools sufficient to record information about the components and their interdependencies in an enterprise architecture. Third, I will develop network protocol parsers and operating system interrogation tools that will capture the runtime inter-dependencies between components of the enterprise architecture. The simulations will enable me to address H6 – H8.

I will work with the company to conduct a survey of their IT group and of their key business users to collect perceived measures of IS flexibility, value, and project costs. Each component in the IS will be evaluated by two IT specialists in order to reduce measurement error. I will also collect estimated and actual project cost information. The survey will be based on the Duncan (Duncan 1995) and Byrd (Byrd and Turner 2000). These measures, in combination with the automated collection of the emergent architecture, will enable me to address H2 and H3.

Following the protocols developed by Yin (Yin 1994), I will conduct semi-structured interviews to better understand the conditions that give rise to observed architectural features. The coded interviews will enable me to address H1, H4, and H5.

METHOD

I will aggregate the multiple respondent measures of system and value perceptions to produce per system aggregate variable values in order to subsequently run a seemingly unrelated regression (SUR) model of multiple dependent variables using the same independent variables.

I will develop a protocol to code and analyze the structured interviews in order to answer the questions that require respondent interpretation and qualitative analysis.

LIMITATIONS AND FUTURE WORK

This work is limited by the cross-sectional nature of data gathering. Future plans include monitoring system emergence over time so that antecedents and consequences of re-architecting can be observed quantitatively. This project is limited by the lack of detailed cost data by which the architectural investment support tool can be calibrated to fit a particular company.

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