Whole System Design and Evolutionary 21st Century American Buildings + Infrastructure

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A Dissertation submitted to

The Faculty of
The School of Engineering and Applied Science
of The George Washington University
in partial satisfaction of the requirements
for the degree of Doctor of Philosophy

August 31, 2013

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Dedication

This dissertation is dedicated to my best friend and beloved husband, Hans.

Acknowledgements

With sincere appreciation, Dr. Shahram Sarkani and Dr. Thomas A. Mazzuchi, Dissertation Co-Directors and Professors of Engineering Management and Systems Engineering at The George Washington University, and staff, Sara and Michelle, are acknowledged for their continued support, positive guidance and endless encouragement. Dissertation Research Committee members, Dr. Edward Lile Murphree, Jr. (Chair), Dr. John Bischoff and Dr. Reza Eftekari are acknowledged for their insights and important input. With gratitude, Dr. Daniel Halpin and Captain John P. Franz, P.E. (my husband who also accompanied me to Japan) are acknowledged for their encouragement at my final exam.

Support of this research by Ms. Janice L. Tuchman, Editor-in-Chief, Engineering News Record (McGraw-Hill Construction) and Mr. Scott Blair, Regional Editor, Engineering News Record California, and the participating project managers is greatly appreciated. With gratitude, Dr. Kenneth Yeang, Dr. Fiona Charnley, and Dr. Donald Norman are acknowledged for their expressed interest and support of this study's expanded model for whole system design. Dr. Thomas Bersson also is acknowledged for his work on applying systems engineering models to sustainable design.

My professors, Dr. David Rico, Dr. Charlie Bixler, Dr. S. Gulu Gambhir, Dr. Andrew McDonald, Dr. Christopher Willy, and Dr. William Roberts, Dr. Enrique Campos-Nanez, Dr. Salim Zafar, and cohort are acknowledged for their guidance and encouragement.

I deeply appreciate the support and patience of my family, friends and colleagues: Mom (Dad and James), Jared, Ingrid, Alexa, Christina, and Peter; Stephen and Christine; Michelle, Bruce, Kevin, Marina, Alesia and Betsy – thank you!

Abstract of Dissertation

Whole System Design and Evolutionary 21st Century American Buildings + Infrastructure

This study explores whole system design and evolutionary 21st century American buildings + infrastructure. The ideas and findings of this dissertation research, as presented at the Seventh International Conference on Design Principles and Practices in Chiba, Japan on March 6, 2013, are provided in a forthcoming publication by the authors (Franz, Sarkani, and Mazzuchi 2013).

Since the introduction of the theory of ecological design in the mid-1970s, whole system design, based on collaboration, research, new technologies and iterative value management, has been increasingly applied to drive sustainable and more innovative solutions (Franz 2011, 2012). While this systems engineering approach for achieving substantial environmental and economic benefits is more commonplace today, it is theorized that evolutionary buildings + infrastructure are achieved through an expanded model of whole system design, one combining art and science, and disciplined processes for the purpose of innovation and differentiation (Franz, Sarkani, and Mazzuchi 2013). This model integrating whole system design (integrated design) with project management, systems engineering process models and radial innovation drives design innovation, promotes change in the built environment and prompts new market opportunities for the Architect Engineer and Construction industry (Franz, Sarkani, and Mazzuchi 2013).

Franz, Sarkani, and Mazzuchi (2013) note that understanding critical success factors for producing distinguished projects is key to sustaining architectural and engineering practice and the building industry. Through quantitative measurement and qualitative case study analyses, the study using winning projects from *Engineering News Record's* (ENR) Best of the Best 2011 Project Awards (as announced on February 13, 2012 in ENR, The 2011 Best of the Best Projects) examines four questions: 1) what are critical success factors for producing evolutionary 21st century buildings + infrastructure? 2) does whole system design enable project success? 3) do systems engineering process models enhance whole system design? and 4) is radical innovation critical for producing evolutionary American buildings + infrastructure? (Franz, Sarkani, and Mazzuchi 2013)

The study indicates that significant evidence exists to support prior research for factors related to people, project activities, barriers and success (Germuenden and Lechler 1997), and that whole system design (Coley and Lemon, 2008, 2009; Charnley, Lemon and Evans, 2011), as implemented through systems engineering process models (Bersson, Mazzuchi, and Sarkani 2012), and radical innovation (Norman and Verganti 2011) additionally are important factors. Case study information suggests that buildings + infrastructure evolve through design innovation, enhanced by an expanded model for whole system design aligning goals, vision, whole system design and outcomes (Franz, Sarkani, and Mazzuchi 2013). The study informs professionals and students about design innovation and effective project delivery strategies strengthened through systems engineering (Franz, Sarkani, and Mazzuchi 2013).

Keywords:* *Critical Success Factors, Whole System Design, Systems Engineering, Radical Innovation

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Chapter 1. Introduction

1.1 Overview

This study explores whole system design and evolutionary 21st century American buildings + infrastructure. The ideas and findings of this dissertation research, as presented at the Seventh International Conference on Design Principles and Practices in Chiba, Japan on March 6, 2013, are provided in a forthcoming publication by the authors (Franz, Sarkani, and Mazzuchi 2013). Therefore, excerpted material of the publication is appropriately referenced in this manuscript but not typically shown in direct quotes.

Since the introduction of the theory of ecological design in the mid-1970s, whole system design, based on collaboration, research, new technologies and iterative value management, has been increasingly applied to drive sustainable and more innovative solutions (Franz 2011, 2012). While this systems engineering approach for achieving substantial environmental and economic benefits is more commonplace today, it is theorized that evolutionary buildings + infrastructure are achieved through an expanded model of whole system design, one combining art and science, and disciplined processes for the purpose of innovation and differentiation (Franz, Sarkani, and Mazzuchi 2013). This model integrating whole system design (integrated design) with project management, systems engineering process models and radial innovation drives design innovation, promotes change in the built environment and prompts new market opportunities for the Architect Engineer and Construction industry (Franz, Sarkani, and Mazzuchi 2013).

Each year through a national competition, America’s best buildings and infrastructure projects are recognized by *Engineering News Record* (ENR), a nationally and internationally recognized magazine that highlights architectural and engineering projects, addresses emerging industry topics, and ranks Architect Engineer and Construction firms in the United States (U.S.). Based on an expanded whole system design model, quantitative measurement and qualitative case study analyses of winning projects are undertaken to determine critical success factors and drivers of evolutionary change in the built environment (Franz, Sarkani, and Mazzuchi 2013).

1.2 Significance and Interest

Franz, Sarkani, and Mazzuchi (2013) note as the contemporary need for improving performance, operability and human use/intervention through the integration of technology with buildings + infrastructure continues to grow, whole system design is a significant component not just for sustainability, but design innovation. Additionally, understanding the needs and culture of people and society through design research is vital to discovering new meaning and its significance to the built environment.

The evolution of authentic and meaningful design, promotion of new market opportunities and sustainment of long term profitability are important to the Architect Engineer and Construction industry which depends on competency, brand and market opportunity (Franz, Sarkani, and Mazzuchi (2013). As put forth in his late-1970's writings, Robert Gutman, a leading sociologist known for his study of architectural professional practice, distinguishes architecture from medicine and law, describing it as an entrepreneurial profession (Gutman 1977; Cuff and Wriedt 2010).

Sustainability has driven much of the building industry's innovation and differentiation for the past thirty-five years; however, its full potential and new constructs resulting from design innovation remain unrealized (Franz, Sarkani, and Mazzuchi 2013).

Findings are important to design practice and knowledge management, research and technological advancements, and education. The study informs professionals and students about design innovation, and effective project delivery strategies strengthened through systems engineering (Franz, Sarkani, and Mazzuchi 2013).

1.3 Problem Statement

In the mid-1970's, industry's paradigm shift with the introduction of computers and Kenneth Yeang's theory of ecological design prompted evolutionary change (Franz, Sarkani, and Mazzuchi 2013). Following three publications on bases for ecosystem design, energetics of the built environment and bionics – the use of biological analogies in design (Yeang 1972, 1974a, 1974b), Kenneth Yeang created his theory of ecological design in 1975, then published it in 1980 (Yeang 1980).

Yeang's (1980) design framework, a Partitioned Matrix for Design Consideration, commenced the industry's vigorous focus on sustainability, shifting the paradigm for standard practice, changing the future course of design and establishing sustainability as a new standard for success. His original model for internal interdependencies, total inputs, total outputs and external interdependencies was enhanced by red, grey, blue and green ecoinfrastructures, Figure 1-1 (Yeang 1980, 2009).

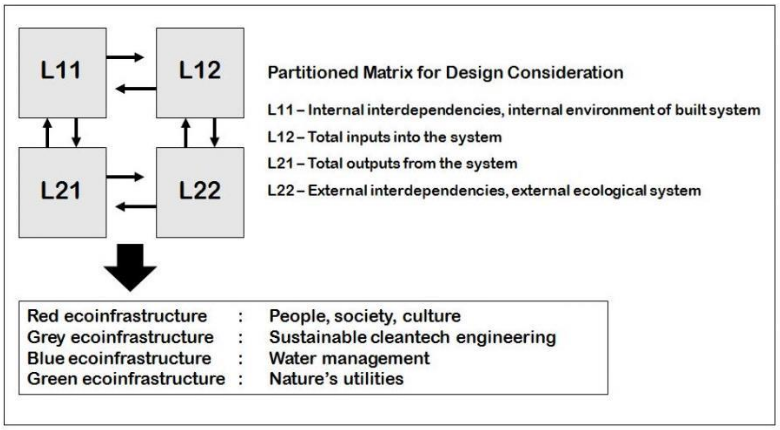

Figure 1-1: Yeang's Theory of Ecological Design
Source: Yeang 1980, 2009; Franz, Sarkani, and Mazzuchi 2013

This study builds on Yeang's foundational work (Yeang 1980, 2009) and other whole system design research (Coley and Lemon 2008, 2009; Charnley, Lemon, and Evans 2011; Blizzard and Klotz 2012). These studies, along with industry recommendations and certification systems, such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED), propose frameworks for ecological considerations in the design and construction of the built environment, factors that enable or inhibit whole system design, and conceptual approaches to whole system design based on extensive literature review. This prior research is focused on design, applying guiding principles and emerging technology.

An empirical study documenting an expanded model of whole system design as it relates to the Architect Engineer and Construction industry has not been undertaken. From conception of an idea to design and construction of the built environment, art and science, and disciplined processes are aligned through whole system design for the purpose of innovation and differentiation (Franz, Sarkani, and Mazzuchi 2013).

Understanding critical success factors for producing such distinguished projects is key to sustaining architectural and engineering practice and the building industry. Through quantitative measurement and qualitative case study analyses, the study examines winning projects, the dependent variable, from ENR's Best of the Best 2011 Project Awards (as announced on February 13, 2012 in ENR, The 2011 Best of the Best Projects). Four research questions are addressed: 1) what are critical success factors for producing evolutionary 21st century buildings + infrastructure? 2) does whole system design enable project success? 3) do systems engineering process models enhance whole system design? and 4) is radical innovation critical for producing evolutionary American buildings + infrastructure? (Franz, Sarkani, Mazzuchi 2013)

Adapted from Shenhar and Dvir (2007) and as depicted in Figure 1-2, this research aims to broaden the concept of whole system design proposing a comprehensive and expanded model where critical success results from a holistic approach aligning goals, vision, whole system design and outcomes (Franz, Sarkani, and Mazzuchi 2013).

GOALS owner/user requirements	VISION content/context/meaning
OUTCOMES efficiency impact on customer and team business and direct success preparation for future	WHOLE SYSTEM DESIGN project management whole system design systems engineering process models radical innovation

Figure 1-2: Goals, Vision, Whole System Design, Outcomes
Source: adapted from Shenhar and Dvir 2007; Franz, Sarkani, and Mazzuchi 2013

1.4 Definitions

1.4.1 Critical Success Factor

Critical success factors are key attributes of people and project activities that pose barriers or enhance project success, as identified by Germuenden and Lechler (1997). As discussed later in Chapter 2, people and project activities enabling or inhibiting project success include, top management, project leader, project team, planning and controlling, participation, information and communications, conflicts and changes of goals (Germuenden and Lechler 1997). Project strategy is a critical success factor (Shenhar and Bonen 1997; Shenhar et al. 2001; Shenhar et al. 2002; Shenhar 2004). Partnering, an accepted Architect Engineer and Construction industry best practice (Construction Industry Institute 2012), also was included in this study.

1.4.2 Whole System Design

The definition for whole systems design is evolving. For clarity, this evolving definition is traced below and concludes with the definition for the expanded model that is the focus of this study. According to the Rocky Mountain Institute (RMI), whole system design means,

> Optimizing not just parts but the entire system. It takes ingenuity, intuition, and teamwork. Everything considered simultaneously and analyzed to reveal mutually advantageous interactions (synergies) as well as undesirable ones. (RMI 2004, 7)

Following case study research exploring the process of whole system design, Charnley, Lemon and Evans refined the definition,

> Whole system design is an integrated and emergent approach to the design of more radically innovative and sustainable solutions. It encourages those involved to look at a problem as a whole; take multiple factors into account and utilize relationships between different parts of the problem as opposed to addressing one aspect at a time. (Charnley, Lemon, and Evans 2011, 172)

Blizzard and Klotz adapted the definition for whole system design to broaden its applicability across many design disciplines,

> Whole systems design considers an entire system as a whole from multiple perspectives to understand how its parts can work together as a system to create synergies and solve multiple design problems simultaneously. It is an interdisciplinary, collaborative and iterative process. (Blizzard and Klotz 2012, 458)

This study adopts the Charnley, Lemon and Evans (2011) whole system design enabling and inhibiting factors (outlined in Chapter 2) and aims to expand the whole system design model beyond sustainability (Franz, Sarkani, and Mazzuchi 2013). In the Franz, Sarkani, and Mazzuchi (2013) model, whole system design encompasses the entire process from definition of owner/client requirements, identification of a vision for content, context and meaning, development through whole system design (project management and project strategy, whole system design (integrated design, including industry partnerships), systems engineering process models, and radical innovation to project outcomes. The model embraces whole system design as an interdisciplinary, collaborative, and iterative process (Blizzard and Klotz, 2012) resulting in holistic design and strategies that result in value added solutions. This process drives design thinking and design innovation enabling the built environment to respond positively to both the environment and human needs in ways never envisioned (Franz, Sarkani, and Mazzuchi 2013). Whole system design combines art and science, and disciplined processes for the purpose of innovation and differentiation, and ultimately evolutionary change (Franz, Sarkani, and Mazzuchi 2013).

1.4.3 Systems Engineering Process Models

Systems engineering process models are conceptual models that describe interdisciplinary International Council on Systems Engineering approaches that enable the realization of successful systems. As described by Sage and Rouse (2009), these models outline highly structured and disciplined engineering processes defining needs, requirements and performance, and synthesizing, validating and executing design through a structured development, implementation, and testing process. Models holistically treat problems from conception through operations and maintenance. Systems engineering process models integrate all disciplines and expertise, accounting for technical and business needs to provide quality and optimized products that over their life-cycles to meet user needs (Sage and Rouse 2009). The three models included in this study, the Waterfall model, the Vee model and the Spiral model, are discussed in Chapter 2.

1.4.4 Radical Innovation

Radical innovation is a change of frame. It is doing "what we did not do before", and results from technology push and technology epiphanies, or meaning driven innovation as opposed to market pull or incremental innovation which are improvements within a given frame of solutions or "doing better what we already do" (Norman and Verganti 2012, 5) . Radical innovation is discussed in Chapter 2.

1.5 Organization of the Dissertation

The dissertation is organized in five chapters. Five appendices provide a sample of the measurement instrument, measurement instrument data, interview semi-structured questions and data, case studies, and industry expert biographies for the panel selecting ENR's 2011 Best of the Best Project Awards.

Chapter 1, Introduction, presents an overview of the topic, summarizes the significance and interest, and outlines the problem statement and research questions. The chapter includes definitions for critical success factors, whole system design, systems engineering process models and radical innovation.

Chapter 2, Literature Review, outlines applicable literature on critical success factors, whole system design, systems engineering and radical innovation. A timeline for whole system design is provided along with other background information on systems based thinking, federal leadership in integrated design and design thinking and service design.

Chapter 3, Research Framework, presents each research question, the relevant literature and associated hypotheses for critical success factors, whole systems design, systems engineering process models and radical innovation.

Chapter 4, Research Methodology, summarizes the approach to the data collection for studying the four research questions. Data is presented and analyzed in the following order. Quantitative data collected through the measurement instrument is summarized and statistically analyzed, a summary of qualitative data areas is mapped to the measurement instrument, and qualitative data from the semi-structured questions and case study analyses is presented.

Chapter 5, Conclusions, provides the study's conclusions for each of the research questions and the authors' original contribution to knowledge. Broad themes from the quantitative and qualitative data are summarized in an enhanced model for whole system design. Recommendations for areas of further study are presented.