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A PROCESS AND COMPETENCY-BASED APPROACH TO HIGH PERFORMANCE BUILDING DESIGN

A Thesis in

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by

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ABSTRACT

High performance buildings are those which achieve energy efficiency coupled with healthy and productive work environments. Currently, the design process for high performance buildings is largely undefined, and is re-invented on a project-by-project basis, as teams of highly specialized and fragmented disciplines are formed for a particular project. The emphasis on energy efficiency and life-cycle costs savings in high performance buildings demands a specialized set of decisions and analyses in addition to collaboration between disciplines that differs considerably from standard practices found in most architectural and engineering firms. While metrics and standards for the final building product such as The Leadership in Energy and Environmental Design (LEED^{TM}) rating system have evolved rapidly, few models of the "integrated design" process for high performance buildings exist. In addition, few tools exist to help project teams plan and manage the design process for high performance buildings.

To improve and articulate the design process of high performance buildings, a representation of the integrated design process and the steps required to evaluate the process have been developed and validated through case study research. The components of the Design Process Evaluation Model for High Performance Buildings (DPEM^{HP}) developed and validated in this research to help teams improve the design process are: (1) determine the building's desired functions and form the team, (2) develop a decision-based design process model, (3) evaluate decisions for time and sequence, (4) identify and evaluate required information for decisions, and (5) identify competencies for process implementation.

Through case study research and interviews, a decision-based Design Process Model (DPM^{HP}) was developed to characterize the key components of the design process for energy systems design in high performance buildings. The model identifies critical decisions, information, commitments and competencies that the design team encounters during the design of high performance buildings. The results of this research provide useful contributions in the areas of design process theory, process modeling, and the delivery of high performance buildings.

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This document closes the latest chapter on my life, and simultaneously creates endless possibilities for the future. To everyone who has helped me, I thank you, I am very appreciative.

Chapter 1

Introduction

1.1 Introduction

This research has examined the design process for high performance buildings. As the demand for “sustainable” or “green” design solutions continues to increase in both public and private facility construction, the need for a better understanding of how cost effective energy and resource efficient buildings are designed and constructed has increased as well. Characterized by technical systems with high levels of interdependency and interaction, high performance buildings demand increased levels of design collaboration and coordination between structural, envelope, mechanical, electrical, and architectural systems during design.

Currently, the design process for high performance buildings is largely undefined and is re-invented on a project-by-project basis. As teams of highly specialized and fragmented disciplines are formed for a particular project, a new design process is developed. As a result, a highly sequential and specialized business practice has evolved for building-design teams, which challenges efforts for collaboration and integration. Processes have been developed that isolate design members in an effort to accommodate frequent team formation and team member changes. While metrics and standards for the final building product such as the Leadership in Energy and Environmental Design (LEED^{TM}) rating system have rapidly evolved, few models of the process of designing a high performance building exist. What is known, however, is that an emphasis on energy efficiency and life-cycle cost savings in high performance buildings emphasizes a set of decisions and analysis that differ considerably from standard practices found in most architectural and engineering firms.

1.2 Conceptual Model of the Design Process to Highlight Issues in the Design Process

The traditional design process is one that fosters the isolation of disciplines during the design and construction process (Kashyap, et al., 2003) (i.e. structural design does not begin until completion of architectural drawings, with both needing to be completed prior to mechanical systems design beginning). This isolation coupled with increasingly fragmented design and construction data typically leads to costly changes, duplicated design efforts, and redundancies in the final design, which results in buildings that operate below their optimum potential. Also adding to the overall waste within the traditional design process are ambiguous procurement processes that lead to undefined roles and/or poorly timed involvement for team members.

As a result of these practices, design information for buildings seems to have declined and become increasingly uncoordinated. The American Council of Engineering Companies (ACEC) has identified many causes for this decrease in document quality (ACEC, 2003), most of which have to do with the fundamental design process. Ill-timed collaborations in the design of high performance buildings have greater consequences than those of a traditional building. While many designers and engineers profess to be “system” thinkers, the reality of specialization, isolated decision-making, conventional delivery methods, and the speed of the building process itself conspire to prevent optimization of most systems that are engaged when buildings are produced (Reed and Gordon, 2000). This thesis postulates the development and articulation of a design process for the design of high performance buildings that will provide a mechanism to aid in superior “system” thinking during the design process.

Many engineering and architecture programs are attempting to narrow the gap in the skill differences between disciplines (Burt Hill Kosar Rittelmann Associates, 2003). With this shift away from specialization, the identification of core competencies (an underlying characteristic of an actor) possessed by various disciplines has become increasingly blurred. Accurate competency identification of teams and individuals is further complicated in high performance building projects because the requirements of the team and individuals involved in the design are different from those for persons designing a traditional building. High performance buildings require an even greater number of functional competencies than a traditional project, and thus place an even greater demand on the distribution of these competencies among team members (Reed and Eisenberg, 2003). The more relevant competencies teams possess throughout a project, however, the more likely the project will succeed (Riley, et al., 2004).

1.2.1 Design Competencies

The rise of specialized disciplines in the building design process in the 1970's introduced a need for effective team integration in the design process. However, we still see today that design information for buildings is increasingly fragmented because it is formulated by isolated specialists in various disciplines. This fragmentation within design disciplines challenges effective decision making by the design team. In many cases, this fragmentation results in sequential design processes as illustrated in Figure 1-1.

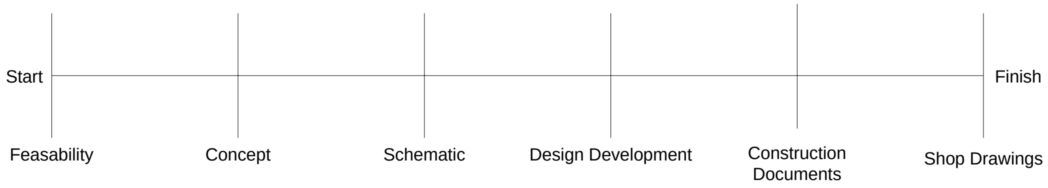


Figure 1-1: AIA Traditional Sequential Design Milestones (Haviland, 1994)

The milestone design approach of the traditional design process has developed significant sources of waste. Koskela and Huovila (1997) characterize waste in terms of minimizing what is unnecessary for task completion and value generation. Examples of this waste include decisions that are ill-timed, poorly sequenced, and misinformed. The next section further explains these types of waste in greater detail.

1.2.2 Design Decisions and Waste

Waste can manifests itself in many forms in the design process for buildings. Thus, identifying the most prevalent forms and causes of waste will enable the design community to improve the design process. An accurate conceptual representation of the design process, such as proposed here, will provide the first step towards this goal. Viewing the design process for high performance buildings as a network of interdependent decisions provides the opportunity to define an under-described environment in a manner that facilitates the evaluation and assessment of the overall design process.

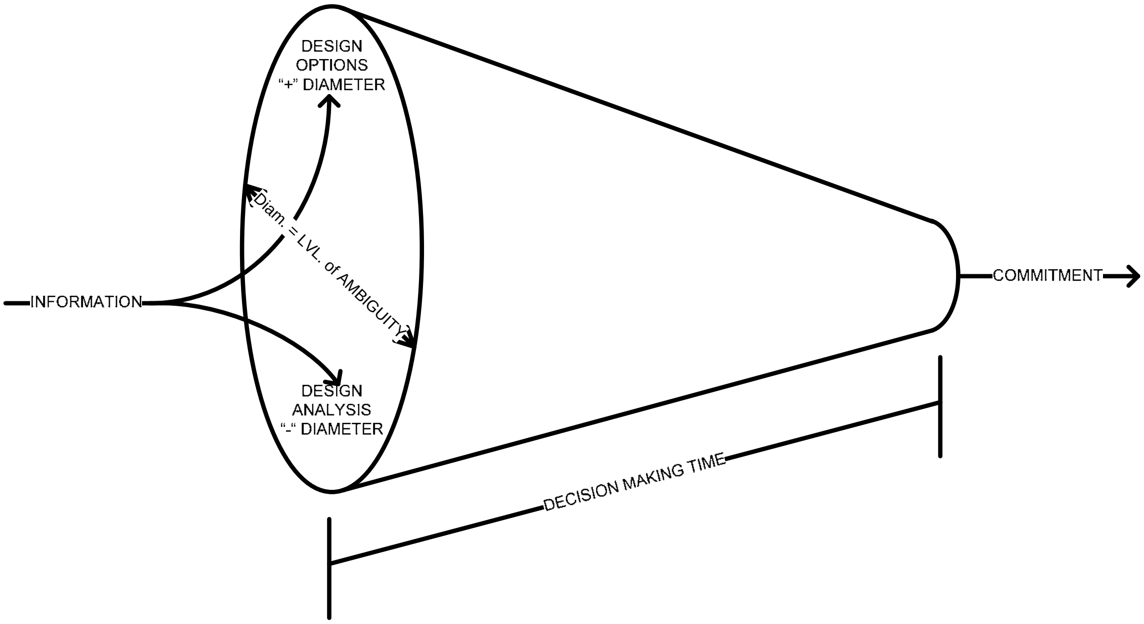


Figure 1-2: Proposed Design-Decision Model

A representation of the conceptual level design-decision model is shown in Figure 1-2. The cone model is used to represent the nature of a decision process in which options are narrowed through analysis and information to a point at which a commitment to one choice is made. Ambiguity in the decision process at any given time within the decision timeline is represented by the diameter of the cone. As new options are presented for consideration, ambiguity is large, as information is gathered, and as analysis of options takes place, ambiguity shrinks. Ultimately, a decision is made resulting in certainty. In some cases, a decision is made with some level of remaining ambiguity. In others, it is made with less ambiguity, and thus with a higher level of certainty. As changes to any decision are likely to create down stream waste in the form of rework, decisions are ideally made with sufficient certainty to be considered *commitments* upon which subsequence decisions can rely.

1.2.3 Design Decision Network

The organization of decisions in an appropriate sequence is necessary to minimize waste in the design of an effective design process. Figure 1-3 represents a conceptual level network of design decisions. As decisions are made the resulting commitments act as information for future decisions in the design process. In addition to decisions, analyses are performed during the design process, providing further information. These activities, or *analyses*, are represented by boxes in the design-decision network and are enablers of decision-making processes. Examples of *analyses* (see Appendix A for glossary of terms) are computer simulations, cost estimates, and research.

All of the design activities take place in the design environment. This environment includes the actions (decisions and analyses) that are made when developing the design, as well as the individuals or actors responsible for the design. The set of skills and knowledge possessed by the individuals responsible for the design directly influence the decisions, information, and analyses that constitute the design decision network. These skills and knowledge are characterized as *competencies* and are represented by a hexagon in the design-decision network.

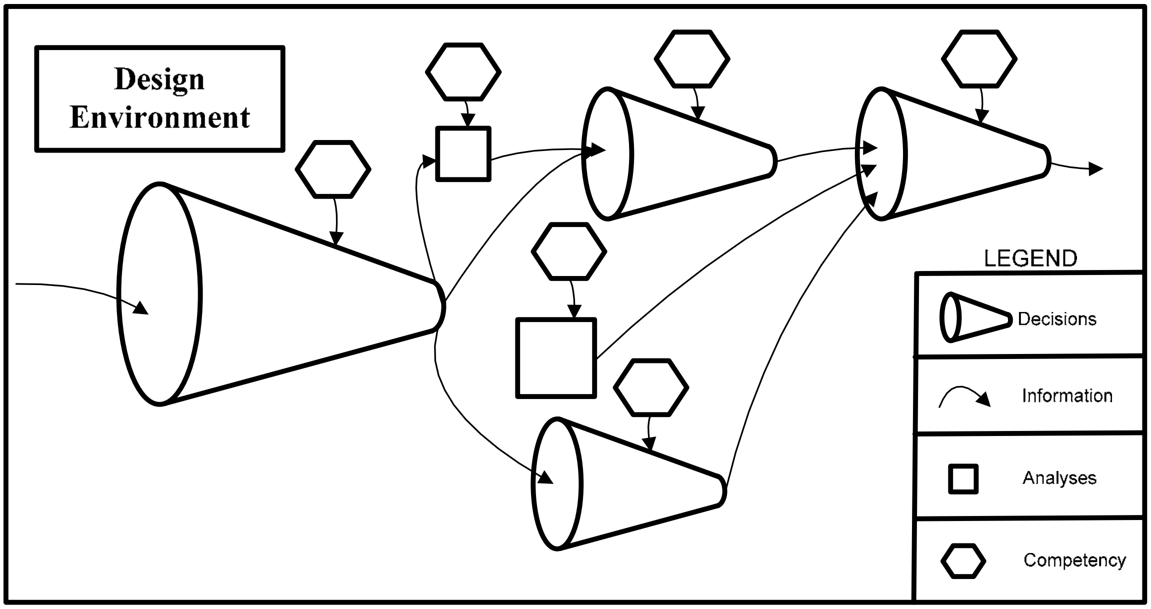


Figure 1-3: Proposed Design Decision Network Model (DDNM)

An emphasis on identifying enabling decisions and competency requirements that inform future decisions can lead to minimization of wasted efforts and delays in the design process. It is also important to note that certain decisions have a higher impact than others on factors such as the ultimate costs of a project or the performance of the project (i.e. building orientation and configuration on the site can significantly impact daylight performance when compared to the impact sun shading design can have on daylighting). Thus a model of the design process should also allow for prioritizing certain decisions above others, and assessing the relative importance of decisions.

1.2.4 Sources of Waste in the Design Process

Causes of waste in the design process can fall into three categories: (1) a lack of appropriate judgment or *competency*, (2) early or late *timing* of decisions, and (3) a lack of appropriate *information* for decisions. These three sources of waste are discussed in more detail.

Missing Design Competencies

The integrated design process for sustainable buildings has been characterized as one that emphasizes the three “E’s”: *early* participation by *everybody* involved in the project design to discuss *everything* having to do with the design (Reed, 2004). Involvement of all team members in the decision making process is an attribute of high performance teams (Kratzenbach and Smith, 2003). On high performance building projects, the presence and timing of the involvement of key competencies and judgment skills are critical. Involving a team member and respective competencies too early or too late in the design process can be wasteful in the process, and ultimately decrease the overall performance of the team and the final building product. For example, by not seeking the advice of an energy expert early in the project, opportunities to minimize energy use in the building might be lost. Conversely, involving too many individuals too early in the process can result in excess costs, increasing the expense associated with all early decisions.

Poor Timing of Decisions

A natural and classic tension exists between the timing of design decisions. A delay in a decision (commitment) allows time for additional information to be gathered and analysis to be performed, which hopefully will result in a better decision. If other decisions (or construction processes) depend on the results of earlier decisions, however, a cost will be associated with the delay. Making a decision too early in the design process may provide needed information for subsequent decisions and processes, but could ultimately have a negative impact on the final building design if it is based on inaccurate assumptions or insufficient analysis. Conversely, if a decision is delayed too long, other dependant decisions will be delayed and the design process and its participants will suffer consequences, such as increased design durations and construction delays. *Thus, the appropriate timing of decision making in the design process is a key factor that must be managed throughout the process.* Currently, there is no mechanism or metric to evaluate the timing of decision making in the design process for high performance buildings. As a result, waste may occur in the process because of ill-timed decisions (i.e. selection of mechanical distribution systems after the selection of the mechanical room location can result in less efficient mechanical systems leading to redesign to optimize the design).

Figure 1-4 illustrates different timing of decisions in the proposed conceptual level design decision model. A decision that is made without enough information (or with too much ambiguity) is represented as a Level I decision. Making a Level I decision can cause process and product waste, whereby inappropriate commitments are made that lead to misinformed decisions, for example, when excess safety factors are included throughout the duration of design in the sizing of systems because the required information is not available.

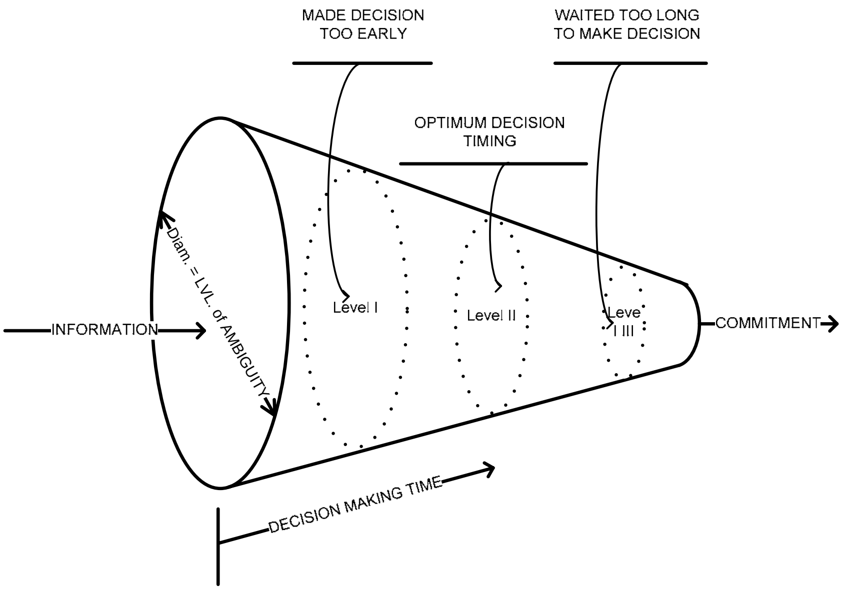


Figure 1-4: Proposed Design Decision Timing Model

Level III decisions are made after the optimum time to make a decision has passed and extra time has been spent reducing the level of ambiguity surrounding the final commitment. An example of waste resulting from Level III decisions include rework in downstream commitments that proceeded while waiting for a commitment from the Level III decision.

Level II decisions represent an optimum time to make a commitment. The level of ambiguity has been sufficiently decreased to allow for an appropriately informed decision, and additional waste has not been introduced to the decision-making process by prolonging the timing of the commitment. In the high performance design process, teams should strive to make decisions that are Level II in nature. Decisions that are not made at this level result in product or process waste for the project. In terms of traditional decision-making theory, such as Real Options Theory, this is the equivalent of the point at which the marginal benefit of making the decision is equal to the marginal cost of waiting to make the decision (Neufville, 2001).

Missing Information for Decisions

A third source of waste in the design process is a decision made without the appropriate information. This lack of information may not be understood at the time of the decision, or be caused by a lack of knowledge on the part of the project team. In some cases, it may be in the form of an assumption made to allow other decisions or work to proceed in the event of a prior decision being delayed. Decisions made without sufficient information can often lead to changes in design decisions, and essentially to breaking a commitment on which others have relied. This well-known source of waste and added cost is well understood in the building industry.

The current lack of design process guidance can lead to sub-optimal decisions that result in a repeat of the same mistakes on each new project. These mistakes result in increasingly fragmented design and construction data that cause costly changes, unnecessary rework in design, as well as construction and buildings that operate at levels far below optimum (ACEC, 2003).

The proposed conceptual level design decision-making model helps illustrate the need for a decision evaluation model that will lead to reduction in mistakes in the design process for high performance buildings.

1.3 Problem Statement

Understanding the design process as a network of decisions reveals current models of the building design process provide little more than a coarse set of milestones, broad categories of design decisions, and sequential building systems analysis. While the need for an integrated design has been established in high performance buildings (USGBC, 2003), the actual design process for high performance buildings is especially undefined. In practice, newly formed design teams incur process waste that detracts from the design analysis and final building design. A better definition of the design process for high performance buildings that stresses the integration between systems, and accounts for the key processes and competencies vital to appropriate design decisions will help reduce design process waste and increase design quality.

Applying a decision oriented process and competency-based method to evaluate the design process will provide a description model of the integrated design process especially useful for high performance buildings as it will identify process waste and opportunities to increase design quality.

1.4 Goal and Objectives

The goal in this research is to provide a methodology to evaluate continuously and improve the value, relationship, and timing of decisions in the design process of high performance buildings through a reduction in design process waste. This will be attained through the development of four objectives and accomplishment of specific tasks related to each objective. The specific objectives and associated tasks of this research are:

1) Identify current requirements and practices in high performance building design:

- Review relevant literature
- Participate in a roundtable discussion of the design process for sustainable buildings attended by leading designers of sustainable buildings

- Conduct case study research on the design process of three high performance buildings
- Verify that current design process models are inadequate in their ability to encompass the special requirements of the design process for high performance buildings
- Compile a list of key activities required in the design of high performance buildings

2) Validate the decision-based design characterization of high performance building design:

- Develop a proposition-based case study research approach for high performance buildings to test the decision based characterization
- Collect project data through key participant interviews and relevant document review
- Analyze the data and determine validation for the propositions developed

3) Develop a methodology to assess the timing and sequencing of key decisions required to achieve a high performance design process:

- Select an existing design-process modeling methodology that can be improved to consider the special requirements of the design process for high performance buildings
- Construct a methodical approach to analyze the chosen design process and identify changes required to improve the decision-making capabilities through an overall reduction in waste, improved value-added decisions during the design process, integration of appropriate multidisciplinary interactions, and proper timing of collaborations to decrease participant dependencies.

4) Provide a competency-based tool that aids in the implementation of research findings in the practice of high performance building design:

- Initially identify core competency requirements of the design process for high performance buildings
- Develop a tool that highlights the key components of the high performance design process including key cross-disciplinary collaborations, the proper timing for these collaborations, and core competency requirements of each activity
- Provide a mechanism by which building project teams can evaluate alignment between the high performance design process and the key competencies required throughout the process.

1.5 Summary and Readers Guide

Currently, the design process for high performance buildings is largely undefined, and is re-invented on a project-by-project basis, as teams from highly specialized disciplines are formed. While metrics for the final building product such as the LEED^{TM} rating system have evolved rapidly, few design process models for high performance buildings exist. To address this issue, this research will develop a methodology to improve continuously the value, relationship, and timing of decisions in the design process of high performance buildings, through a reduction in design process waste.

A conceptual level model of the decision-making process for building design has been proposed and objectives introduced that, when accomplished, will provide an improved evaluation and implementation technique for the building design process for high performance buildings. In Chapter 2, the results of a review of relevant literature and current practices are presented. Chapter 3 presents the research methods used. The development of propositions for case study research is presented in Chapter 4. Data collection and testing is presented in Chapter 5, followed by proposition validation in Chapter 6. Chapter 7 presents the development of a design process evaluation model. Conclusions are presented in Chapter 8.

Chapter 2

Background Research and Relevant Literature

2.1 Introduction

This literature review is based on the premise that the design process is made up of a network of decisions, which has not yet been defined for the design of high performance buildings. A discussion of widely accepted decision-making theories from the field of manufacturing and their relation to this current research is provided in this chapter. In addition to the discussion on decision based design theory, the results of an investigation into the other vital components of the research are presented.

Initially the chapter explains the current concepts in the literature that are part of the research that was conducted for this study. However, a thorough understanding of sustainable and high performance buildings and building design processes is needed before the primary research question can be presented as it was investigated using a case study for this research. The definition and differentiators of sustainable and high performance buildings are provided so as to create a context within which the design process discussion for high performance buildings can occur. Traditional building design process attributes are then compared to the design approach for sustainable and high performance buildings, with key contrasts provided. A review of the currently accepted process modeling techniques for building design is presented, and the reason for selecting the technique used for this research is explained.

After the discussion of decision making and decision-based design engineering, the concurrent engineering and lean production literature are reviewed and a basic understanding of each is presented to provide the fundamental theories upon which the case study propositions for this study have been developed.

The final portion of the literature review provides information on the individual and team competency identification techniques that exist and describes a systematic methodology to identify individual and team competency requirements.

2.1.1 Building Design Process

The traditional building design process is one that is similar to the "over-the-wall" approach in manufacturing design (Evbuomwan and Anuba, 1998); it fosters an isolation of disciplines during design and construction. This isolation of design disciplines, coupled with increasingly fragmented design and construction data, typically leads to costly changes, unnecessary rework in design, as well as construction and buildings that operate at levels far below optimum. Also adding to the overall waste within the traditional design process is ambiguous procurement processes that often lead to unclear or inappropriate roles for each project team member (Kashyap, et al., 2003).

While many designers and engineers profess to be "systems" thinkers, the reality of specialization, isolated decision making, conventional practice methods, and the speed of the building process conspire to prevent achievable optimization of almost every system engaged when buildings are constructed (Reed and Gordon, 2000). The articulation of an effective decision-making model for high performance building design is needed to provide a mechanism to aid in "systems" thinking during the design process.

There is considerable agreement among those in the field of sustainable design that cross-disciplinary teamwork early in the design process is essential for achieving the successful integration of building, community, natural, and economic systems (Reed and Gordon, 2000). There is equal agreement that the success of the project is largely influenced by the interactions within the team throughout the design process. In the context of sustainable design, interactions are increased between team members, and thus interpersonal skills become more critical than in the traditional process (BHKR, 2003).

Mendler and Odell (2000) note numerous guidebooks have been published that focus on the technical aspects of sustainable design, but very little has been published to describe the design process itself. Even so, an integrated design approach has gained widespread acceptance in the field of sustainable design. This approach focuses on increasing the levels of design integration in an effort to improve system design optimization. The integrated design approach aims to involve everyone to discuss everything early in the process. Most often this is accomplished through an Eco-Charette (multi-disciplinary collaborative design event to discuss sustainable design issues) at the beginning of the project. Little research has been performed to identify methods to increase sustainability input after conceptual design and through construction, especially from the members of the project team managing and performing the work.

Reduced consumption of resources is a major emphasis of high performance buildings, thus making the design of low-energy systems extremely important in the design process. Balancing the performance attributes of the building envelope with those of the mechanical system becomes extremely critical when designing a high performance building (Magent, et al., 2004).

2.1.2 Sustainable/High Performance Buildings

"The term 'green building' is synonymous with 'high-performance building', 'sustainable design and construction', as well as other terms that refer to a holistic approach to design and construction. There are many different conceptions of green building design due to the large scope of sustainability issues and the novelty of sustainable principles" (United States Green Building Council, 2003).

The United States Green Building Council's (USGBC) approach to high performance and sustainable buildings makes differentiating between the two a difficult task. A universally accepted definition of the two does not currently exist. Depending on which definition one considers, it can be easily discernable that a difference exists, or no difference at all might be visible. However, considering four representative and more detailed definitions of sustainable and high performance buildings allows us to identify subtle differences between each. We begin with two definitions of sustainable buildings.

- A sustainable building is a "part of a sustainable development which aims to deliver built assets that enhances quality of life and offers customer satisfaction; offers flexibility and the potential to cater for user changes in the future; provides and supports desirable natural and social environments; and maximizes the efficient use of resources."

  -Raynsford (2000)

- Sustainable construction is "creating a healthy built environment using resource-efficient, ecologically based principles."

  –Chen and Chambers (1999)

- "A high-performance commercial building is a building with energy, economic, and environmental performance that is substantially better than standard practice. It is energy efficient, so it saves money and natural resources. It's a healthy place to live and work for its occupants and has relatively low impact on the environment."

  -United States Department of Energy (DOE, 2003)

- "A high-performance building is one that minimizes resource consumption during design, construction, and over its life, and provides healthy and productive environments for occupants through the application of 'sustainable' or 'green' principles."

  -Riley, et al. (2004)

Representative definitions of sustainable and high performance buildings show that each has many similarities. Both identify the importance of considering resource consumption and creating a healthy place to live. An underlying differentiator between the two, however, is the emphasis each places on the building's operating resource consumption and the quality of the occupant environment (e.g., indoor air quality) relative to other more global environmental topics. Sustainable or green buildings place a greater emphasis on items affecting global ecological issues, and high performance buildings emphasize building resource reduction (Reed and Gordon, 2000).

For the purposes of this research, the following definition for high performance buildings has been developed:

> A high-performance building is one that minimizes resource consumption while providing healthy and productive environments for the occupants and incurs the least possible life cycle costs while minimizing first-time costs through systems integration.

2.2 Decision Making

Viewing the design process as a network of decisions allows the opportunity to define an under-described environment in a manner that facilitates the evaluation and assessment of the overall design process. This approach is an extension of three accepted theories: options-based, wicked problems, and manufacturing's decision-based designs. To date, these theories have not been applied to the design process for high performance buildings; however, certain aspects of each of these theories served as the foundation for this case study research.

2.2.1 Real Options Theory

Real options analysis is a set of procedures adapted from options analysis. Conventionally good design minimizes risk; it focuses on reliability and making the best decisions in risky situations. The framework of options thinking recognizes that uncertainty adds value to options, which can be viewed as a positive element. It seeks out opportunities to add value and commits to ongoing processes of information gathering to ensure that options decisions can be exploited at the correct time (Neufville, 2001).

With options theory based in financial contracts, a new term “real options” was coined to address the physical elements of a system that provide rights, not obligations to achieve some goal or activity. Generally speaking, all elements of a system that provide flexibility can be considered “real options.” In the case of design processes, value added ambiguity in the decision-making process would be considered “real options.”

The most important contribution of options theory to the general public is the development of options analysis. Options analysis consists of a set of procedures for calculating the value of options, and specifically “real options.” The result of an options analysis is a value for a particular option or element of a system, and “real options” analysis leads to approximate rather than precise values.

Engineers are trained to reduce risk to prevent failures. An example of this is clear in the traditional design of an air handling unit for a new building. Decisions on the size of the unit are made early in the design process based on incomplete design information, including conservative building load estimates, wider than needed comfort levels, and inexact occupancy conditions. Typically these decisions are never revisited later in the design process, and the unit is installed in the building as initially designed with the risk reduction factors all still intact.

The real options approach, like the high performance design process, seeks out risky situations. More informed decisions earlier in the design process can lead to more appropriately sized air handling units. The greater the initial uncertainty, the greater the potential for gain through appropriately placed options. This approach therefore aims to identify the parts of the system that may have the most uncertainty and tries to see how these situations can be exploited (Neufville, 2001).

2.2.2 Wicked Problems

Rittel coined the term “wicked” for ill-defined problem sets which are too complex to be solved by rational systematic processes (Rittel and Webber, 1972; Whelton and Ballard, 1999). Rittel defined six characteristics of wicked problems: (1) you don’t understand the problem until you have developed a solution; (2) wicked problems have no stopping rule; (3) solutions to wicked problems are not right or wrong; (4) every wicked problem is essentially unique and novel; (5) every solution to a wicked problem is a "one-shot operation," and (6) wicked problems have no given alternative solution (Conklin, 2003). For building designers, this is all too often the daily environment within which they live.

Conklin and Weil conducted a study that compared the decision-making process of designers involved in an elevator design case study, with the traditional waterfall method of problem solving (see Figure 2-1). The study showed that designers would start by trying to understand a problem, but would immediately jump to formulating potential solutions, a method contrary to the previously perceived notion of waterfall problem solving. A non-linear pattern of problem solving was identified, and a model of the decision-making process in building decisions was created.

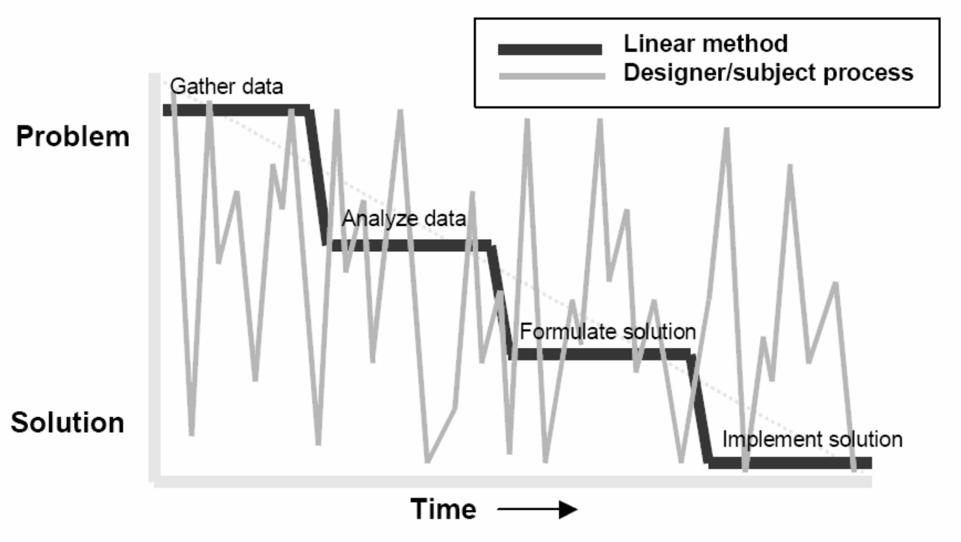


Figure 2-1: Pattern of Cognitive Activity of One Designer – The 'Jagged' Line (Conklin and Weil, 2003)

In addition to providing a model of the decision-making process, the study revealed that the feeling of "wandering all over" in the design process is not a mark of habitude or lack of training. This non-linear process is not a defect, but rather the mark of an intelligent and creative learning process. From another perspective, the jagged line can be viewed as a picture of learning. While this research does not agree that appropriate planning does not enhance the ultimate solution for wicked problems, the notion that ambiguity is not prohibitive of the decision making process but a necessity for creative solutions is aligned with the decision-making process that has been described in Chapter 1.

2.3 Decision-Based Design Engineering

The notion that design has come to be thought of as a decision-making process is consistent with the definition of a decision as (1) a choice from among a set (either closed or open) of options, and (2) an irrevocable allocation of resources. Decision-Based Design (DBD) seeks to base engineering design decisions on information obtained from a variety of sources going well beyond the engineering disciplines. The preferred decision is the option whose expectation has the highest value. Classical decision theory applies to the case where a known set of options has been defined, and design is a decision that seeks to maximize value (Hazelrigg, 1998).

Decision-based design is a term coined to emphasize a different perspective from which to develop methods for design. The principal role of a designer in DBD is to make decisions, and decisions help bridge the gap between an idea and reality. In DBD, decisions serve as markers to identify the progression of a design from initiation to implementation to termination (Mistree and Allen, 1997).

The body of knowledge on making rational design decisions from a performance point of view originates from ideas presented by Herbert A. Simon in *The Sciences of the Artificial* (Simon, 1969). Many models of the engineering design process have been created. A good overview of some of these models is provided by Cross (1994) who describes the process models introduced by French, Archer, Pahl, and Beitz, and his own model in some detail. Birmingham (1997) describes the models of Hall, Darke, Lawson, March, Pahl, and Beitzm, Pugh and Cross. Van der Kroonenberg and Siers (1992) describe models by Hansen, Krick, Asimow, Rodenacker, Matousek, Roth, and Koller as well. As most authors indicate, no universally accepted model of the design process has emerged from these studies.

The heightened importance in collaboration between disciplines in the integrated design process raises the need to develop a common design process vernacular for both engineers and architects. In general, engineering models of the design process are more linear, prescriptive, and tree-like, having a well-defined sequence of stages, resting on an exhaustive evaluation of requirements, and basically deal with a well-defined problem. Architectural process models tend to be more cyclical, descriptive, and lattice-like, allowing for many process cycles, based on partly implicit and changing requirements and relying on tacit knowledge (De Wilde, et al., 2002).

2.3.1 Pugh's Concept Generation and Selection Process

Pugh's method for controlled convergence (see Figure 2-2) is closely aligned with the DDNM at a general level. Both offer a model that provides a means to arrive at a final decision through the introduction of new concepts and the reduction of existing concepts. Pugh focuses on alternate convergence (decreasing cone diameter) and divergent thinking (increasing cone diameter) as a means to decrease the initial number of concepts and add new concepts during the concept selection process (Pugh, 1990). The DDNM uses the same graphical representation (increasing/decreasing cone diameter) to represent the level of ambiguity present in the decision-making process of design.

Pugh starts with multiple solutions to the problem and tries to select the best. The DDNM focuses on processing the information present in the design process, the decisions that result, and the corresponding commitments needed to generate the optimum solution to the problem. The DDNM also demonstrates a way to organize the activities required to develop the optimum design solution. Pugh's model can sort out ideas, but not accurately depict the design process and its corresponding activities with the same level of detail as the design-decision model.

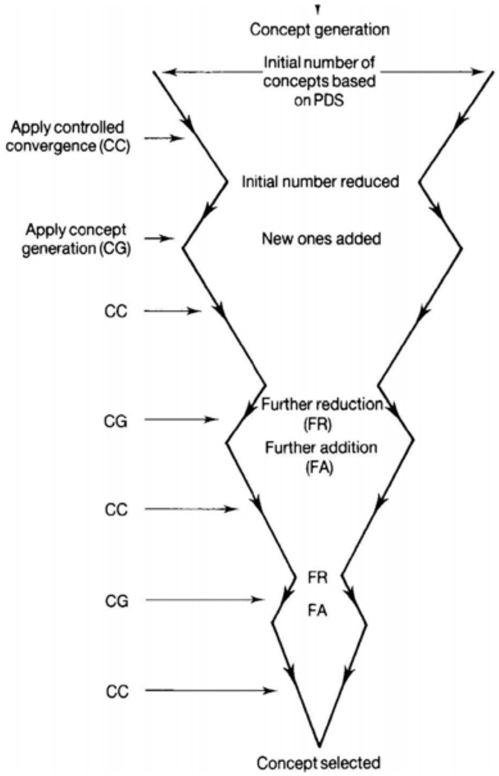


Figure 2-2: Pugh's Concept Generation and Selection Process (Pugh, 1990)

2.3.2 Shooter's Conical Information Flow Model for Design

Shooter's Conical Information Flow Model (see Figure 2-3) and the DDNM both represent the flow of information in the design process and the resultant final design. Both represent the information development that leads to the final design. Shooter's model focuses on information as the description of the product being designed. As the information increases, the product design is closer to completion. This is in contrast to the DDNM that views information as the catalyst for the resulting decisions that lead to commitments during the design process. The DDNM addresses the need to provide a mechanism to evaluate the appropriateness of the timing of decisions (Level I, II, and III) whereas Shooter's model does not (Shooter, et al., 2000).

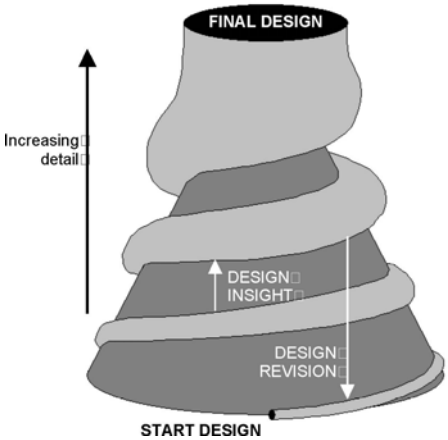


Figure 2-3: Conical Information Flow Model for Design (Shooter, et al., 2000)

Shooter's Conical Information Flow Model does not act as a design process model; rather it simply emphasizes the information flow in the design process. The DDNM provides a means of viewing the information flow, the decisions, and the resulting commitments in a manner that is easily converted to the key decisions that make up the design process.

2.3.3 Suh's Spiraling Design Helix

Suh's Spiraling Design Helix (see Figure 2-4) is a macro level representation of the design process compared to the DDNM. It considers where design fits into a societal context and represents the chaotic rather than systematic process of the design world through a helix depiction. Suh's helix shows that oftentimes the roles of design, marketing, and manufacturing as multiple starting points in the design process conflict (Suh, 1990). Compared to Suh's Spiraling Design Helix, the DDNM is a micro level design process model representation. It represents the *design process* activities of a project by modeling the information flow required of each to make decisions and resulting commitments. Manufacturing and marketing requirements for buildings are considered through competency analysis in the DDNM. An example would be the inclusion of the technical competency constructability knowledge during design. The introduction of this competency during design enhances the design through improved construction (manufacturing) capabilities.

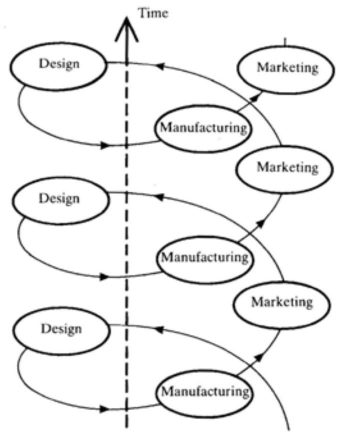


Figure 2-4: Suh's Spiraling Design Helix (Suh, 1990)

2.3.4 Hollins and Pugh's Spectrum of Design Activity

Hollins and Pugh's Spectrum of Design Activity (see Figure 2-5) illustrates the relationship between design innovation and the direct expansion of options relative to the innovative nature of the design. The graph shows that as a product design deviates from conventional practices, the number of options considered when developing a complete design increases. This scenario decreases the likelihood of computer use for repetitive analysis and activities.

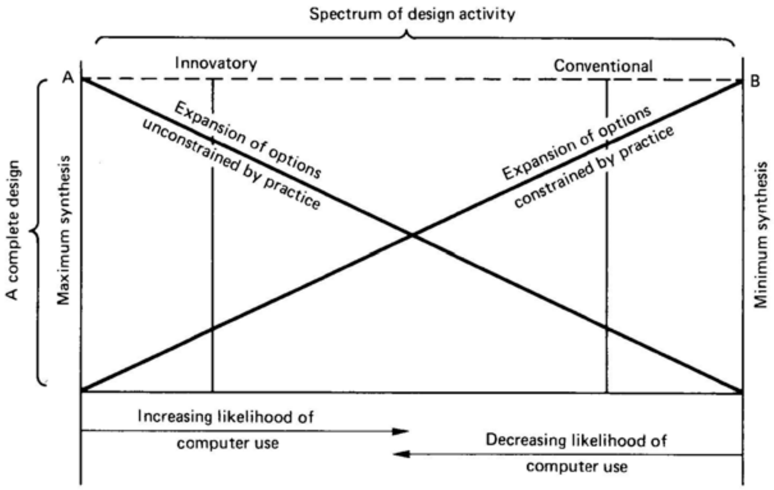


Figure 2-5: Spectrum of Design Activity (Hollins and Pugh, 1990)

Because of the innovative nature of the high performance design, it is anticipated that the amount of information and number of decisions required to produce a complete design will increase. The DDNM provides an organizing mechanism to address the new relationship of activities and an anticipated increase in information processing and the resultant commitments.

2.4 Modeling Methodology

Several efforts have been made to articulate the building design process (Chung, 1989), the most thorough of which was the Integrated Building Process Model (IBPM) by Sanvido, et al. (1990). Developed using the Integral Definition (IDEF) modeling methodology, this work serves as an excellent comparison in the development of a focused process model on the design of high performance buildings.

Reed and Gorden (2000) provide a description of “integrated design,” referring to an inclusive and collaborative effort among various disciplines. They provide twelve main steps to the integrated design process, the first five of which pertain to the design phases of a project: design problem setting, assembling the team, understanding and communicating the issues, the design charette, and distilling the results. Reed emphasizes that the third step, understanding and communicating design issues, is the most critical as preliminary calculations and analysis occur, and detailed programming issues must be assembled (Riley, et al., 2004). While greater amounts of detail exist in Reed's work for the conceptual phase of design than had previously existed, there is still a need for added detail beyond the early phases of design of high performance buildings. Three scientific modeling methodologies have been reviewed and analyzed in order to determine the best technique to use in the research.

Three process modeling techniques—the critical path method (CPM), IDEF, and simulation network model—are presented and their respective advantages and disadvantages (see Table-2-1).

The CPM Schedule Model represents a schedule or project plan as a series of individual operations represented by boxes. Each operation is assigned a duration and appropriate sequential relationship to other operations that must occur directly before or after. These relationships are represented by a line. Through mathematical analysis, the earliest and latest any operation can start is identified, as well as the early and late finish dates, in order to ensure completion by the date determined in the schedule. Costs are assigned to each activity, and overall project cost is considered based on each activity's duration.

An IDEF model represents a process as a series of diagrams. Activities are represented as boxes, and interfaces between activities are depicted as lines with arrows that either enter or exit the activity box. The four kinds of interfaces include inputs, outputs, controls, and mechanisms. Inputs are required to perform the activity, outputs are created when the activity is completed, controls are the conditions or circumstances that govern the activity's performance, and mechanisms are the persons or devices that carry out the activity.

A simulation network model is a high-level representation of a simulation model. For example, Stroboscope combines multiple elements to depict a network (Martinez, 1996). Links connect network nodes and indicate the direction and type of resources that flow through them (depicted as arrows). Nodes represent resources that are either performing a task (activities) or stored and waiting to be used (queues). Activities are depicted by rectangles and queues by circles. A “combi” activity represents tasks that start when certain conditions are met (depicted as rectangles with a missing corner). Table 2-1 provides a summary of Process Modeling Techniques.

The Integrated Definition Method (IDEF)

For this research, an initial process evaluation model has been created for the energy systems design process based on the theory developed in the DDNM. It has been decided that the process modeling tool needs to be as simple as possible, have the ability to address team competency requirements in the design process, adequately consider the decision-making process of high performance buildings, illustrate the basic dependencies between decisions and available information and the mechanisms needed to generate commitments, and allow for a comparison to the IBPM. After a thorough review of modeling techniques including Hierarchy Plus Input-Process-Output (HIPO), Structure Charts, Date Flow Diagrams (DFD), Structured Analysis and Design Technique, Systematic Activity Modeling Method, Warnier/Orr Diagrams, Jackson Diagrams, Simulation Network Models, and Critical Path Method, a detailed comparison and detailed analysis of the three most widely utilized modeling techniques was performed.

IDEF was selected because it best met these requirements. The IDEF model represents a process as a series of diagrams. It describes mainly the informational relationships between activities. In these diagrams the activities that make up the process are depicted as boxes. Interfaces between the activities are depicted as lines with arrows that either enter or exit an activity box.

Four kinds of interfaces are distinguished:

Input: Information or objects required to perform activities
Output: Information or objects that are created when an activity is performed
Control: Conditions or circumstances that govern the activities performed
Mechanism: Persons or devices that carry out the activity

Table 2-1: Modeling Technique Comparison

	CPM Schedule Model	**IDEF Process Models**	**Simulation Network Models**
Main Purpose	Provides a representation of a plan depicting the sequence and integration of all components in determining the best overall program of operation from a cost and schedule perspective.	Provides engineering methods for analyzing and designing complex systems and is used to understand and manage such systems.	Provides a diagrammatic representation of a program or plan for a particular operation that shows the correct sequence and relationship of activities and events required to achieve the final objective.
Limitations	Inability to address the contributing information and objects that inter-relate the activities making up the project plan.	Missing cost/schedule functions that consider process expenses and the costs associated with the process.	Inability to consider cost/schedule functions and the contributing information and objects for each nodal resource
Advantages	Logical mathematical model of a project Provides a graphical representation of activity sequences May be as detailed as needed to anticipate hazards and unexpected conditions of a project Permits systematic reviewing during the project and reevaluation of future uncertainties Identifies the activities determined to be critical based on activity sequence and durations	Produces a structured representation of the functions of a system and the information and objects which interrelate the functions Displays a sequence of activities graphically Easily communicated models based on the activity number restrictions (3-6 activities per level) Provides a graphical representation of activity sequences	Produces a structured representation of the required activities of a network The flow of a specific activity is easily identified by tracing the links through the network Displays a sequence of activities graphically
Disadvantages	Used on specific projects not able to effectively generalize a process and predict results Activity based approach becomes very complex with the addition of many activities at the same level leading to potential misuse in the project evaluation phase Unable to accommodate interdependent tasks No way to represent the information and objects that interrelate to the activities	Inability to address time dynamics Inability to address cost dynamics No mathematical model of the process Difficult to trace the flow of a specific activity through the process Unable to accurately represent detailed and complex processes Focus on activities that require input and produce output making it less suited to capture informal communication patterns and iterations between different process levels.	Inability to address time dynamics Inability to address cost dynamics No mathematical model of the process No way to represent the information and objects that interrelate to the activities

Inputs enter activities from the left, controls from the top, mechanisms from the bottom, and outputs leave activities from the right (see Figure 2-6). IDEF uses a hierarchy of diagrams. One top-level diagram (e.g. A0) shows the process as one activity only; this activity is broken down into more detailed diagrams (e.g. A1, A2, A3, …) that can themselves be decomposed until the tasks are described at a level necessary to support the goal of the process model.

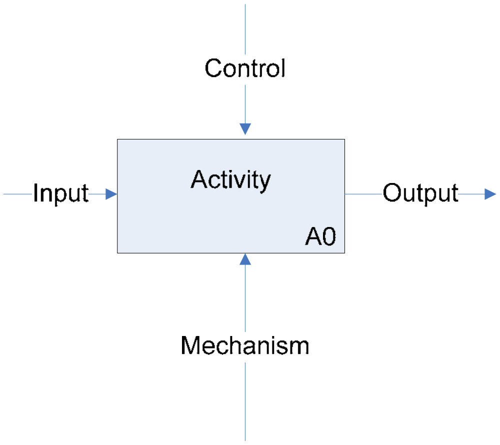


Figure 2-6: IDEF Representation of Concepts and Activities

2.5 Lean Production and Work Structuring

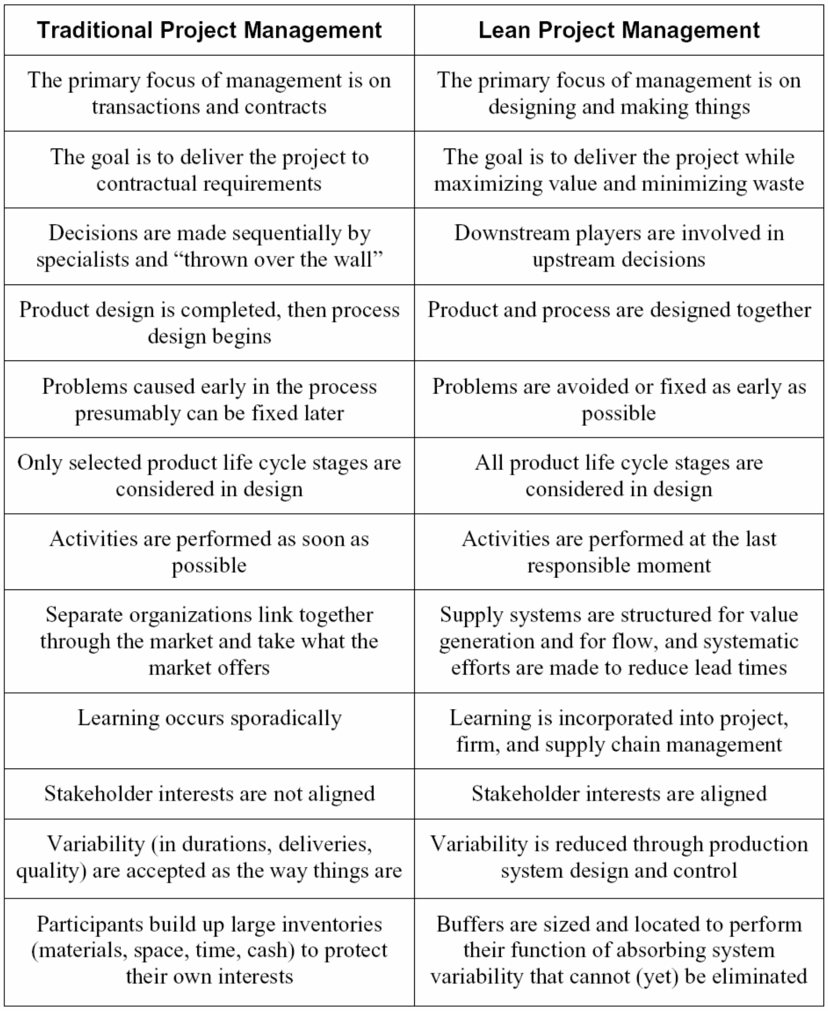
Lean production emphasizes the elimination of waste in the production process to improve the performance of the production system. Lean production places an emphasis on producing products valuable to the customer, while eliminating all other activities defined as waste. While sustainability and lean production both focus on eliminating resource waste, sustainability focuses on the design of the building and lean production on the processes used for realizing the building (Horman, et al., 2004). In an effort to improve the opportunity for waste reduction, Womack and Jones (1996) developed five key lean concepts that are applicable to any environment where a customer expects a particular product resulting from the completion of a process:

1. Specify what does and does not create value from a customer’s perspective
2. Identify the steps necessary to produce the product desired by the customer
3. Make those necessary actions flow without interruption
4. Produce only what is *pulled* by the customer
5. Strive for perfection by continuously improving the process

The traditional principles of project management presented in the Project Management Institute’s Body of Knowledge (PMI 2004) has been compared to a lean construction approach (Koskela, et al., 2002; Ballard, et al., 2002) revealing differences between the two (Tommelein and Ballard, 2004). The results are shown in Table 2-2.

Houvila, et al., (1998) proposed a conceptual framework for managing the design process in which three different views are considered: (1) design as a conversion of inputs and outputs, (2) design as a flow of information, and (3) design as a value generation process for clients.

Table 2-2: Traditional versus Lean Project Management



Traditional Project Management	Lean Project Management
The primary focus of management is on transactions and contracts	The primary focus of management is on designing and making things
The goal is to deliver the project to contractual requirements	The goal is to deliver the project while maximizing value and minimizing waste
Decisions are made sequentially by specialists and "thrown over the wall"	Downstream players are involved in upstream decisions
Product design is completed, then process design begins	Product and process are designed together
Problems caused early in the process presumably can be fixed later	Problems are avoided or fixed as early as possible
Only selected product life cycle stages are considered in design	All product life cycle stages are considered in design
Activities are performed as soon as possible	Activities are performed at the last responsible moment
Separate organizations link together through the market and take what the market offers	Supply systems are structured for value generation and for flow, and systematic efforts are made to reduce lead times
Learning occurs sporadically	Learning is incorporated into project, firm, and supply chain management
Stakeholder interests are not aligned	Stakeholder interests are aligned
Variability (in durations, deliveries, quality) are accepted as the way things are	Variability is reduced through production system design and control
Participants build up large inventories (materials, space, time, cash) to protect their own interests	Buffers are sized and located to perform their function of absorbing system variability that cannot (yet) be eliminated

Research has been proposed to provide an improvement methodology for the traditional design process, based on concepts and principles of lean design (Freire and Alarcon, 2002). The research presented here utilized the current body of work as tools to identify key process activities in the high performance building design process.

2.6 Concurrent Engineering

Concurrent engineering replaces the traditional sequential “over-the-wall” approach to a simultaneous design and manufacturing spectrum with a parallel, less interrelated process (Prasad, 1996).

Concurrent engineering was initially proposed as a concept to reduce product development time (Barkan, 1988; Evans, 1988; Stauffer, 1988; Winner, et al., 1988). Recently, this definition has been broadened to include the integration of the product design, development, manufacturing, and marketing processes. Furthermore, concurrent engineering requires various engineering activities in the product design, development, and production processes to be integrated and performed in a parallel rather than in a sequential manner (Prasad, 1996; Sohlenius, 1992).

The foundation of concurrent engineering is aligned with the principles of integrated design for sustainable buildings. Both place a premium on effective cross-disciplinary collaborations and involvement of appropriate broad ranges of designers. Concurrent engineering provides clearer definitions of the management needs of manufacturing processes than does the integrated design literature to date for design processes.

Considering the fundamental concept of concurrent engineering, AbulHassan (2001) has developed five design phase concurrent engineering guidelines that have been utilized in this research during the Design Process Evaluation Model (DPEM) development. These evaluation filters are:

- The project design team as a whole is responsible for the design, and all members of the project design team are aware of all design activities and decisions
- The team should periodically compare and optimize design project goals and objectives, and eliminate non-value-added functions
- The design must be made on a networked CAD system to facilitate information sharing

- The decision must take into account constructability elements such as construction methods, technology, equipment, and construction sequencing and operations of different contractors
- The design should enable construction of the completed parts of the design without waiting for everything to be fully designed

2.7 Competency Identification

Competencies encompass clusters of skills, knowledge, abilities, and behaviors required for people to succeed (Naughton, 2004). The most comprehensive compilation of professional competencies has been developed by Lombardo and Eichinger (2002) in the book entitled *For Your Improvement*.

Naughton and Rothwell (2004) have further categorized competencies into three layers or categories: foundational competencies, areas of expertise (AEOs), and roles (see Figure 2-7). Foundational competencies are those that are linked to successful performance. These competencies are desirable regardless of an individual's area of

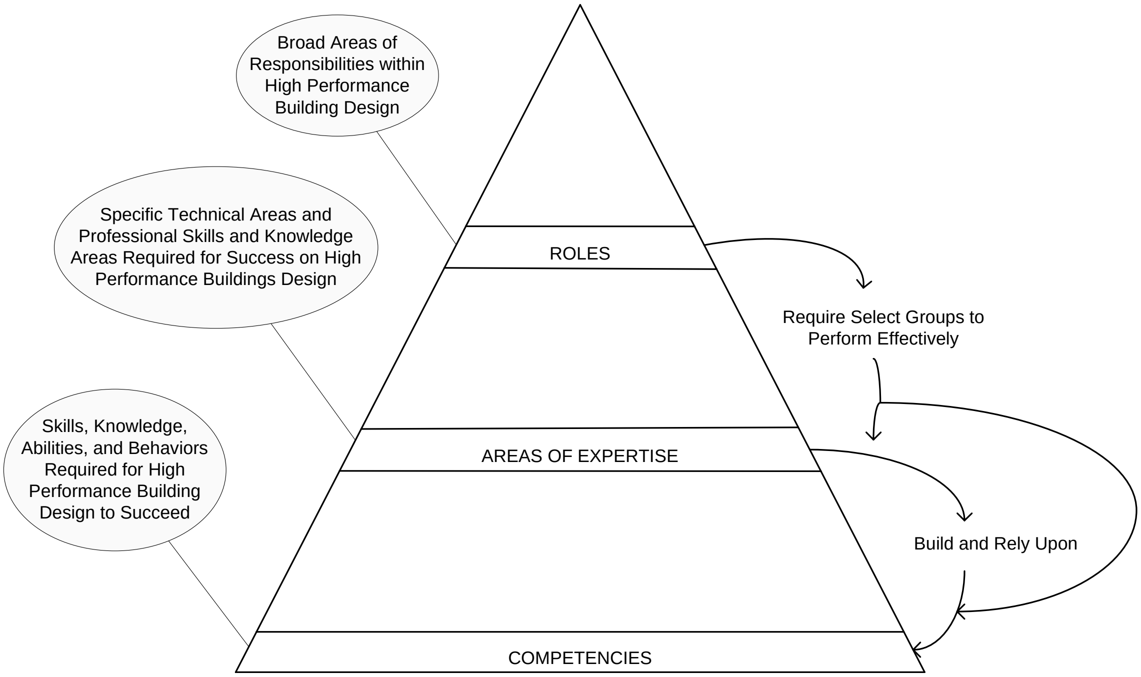


Figure 2-7: Competency Pyramid

expertise (specialization) or role. Areas of expertise are the specific technical and professional skills and knowledge areas required for success in the given field of discussion, and roles are broad areas of responsibility within a field that require a select group of competencies and AOE's to perform effectively.

Competency identification is a task that requires time to reflect back on the operating philosophy of an organization (Shippmann, et al., 2000). In the middle of daily operations, the luxury of reflection is generally not available. The focus on deadlines and milestones often overrides a focus on central operating philosophy. This short-term perspective in the design field has resulted in very limited research on the competency requirements of design professionals, and no research has sought to identify the competency requirements of individuals involved in the design of high performance buildings. A discussion of competencies must begin with careful definitions of important terms, as follows.

Job Competency: An underlying characteristic of an employee (i.e., motive, trait, skill, aspects of one's self-image, social role, or a body of knowledge) which results in effective and/or superior performance on a job (Boyatzis, 1982).

Competency Identification: The process of identifying job competencies (Rothwell and Lindholm, 1999).

Competency Model: The result of competency identification. Competency describes key characteristics that distinguish exemplary performers from fully successful performers (Rothwell and Lindholm, 1999).

Competency Modeling: The process of writing out the results of competency identification by creating a narrative to describe the competencies (Rothwell and Lindholm, 1999).

Both engineering and architecture education are attempting to narrow the gap between the differences in skills each trade possesses compared with the other (Burt Hill Kosar Rittelmann Associates, 2003). With this paradigm shift, the identification of core competencies possessed by various disciplines has become increasingly blurred. Failure to align individual and team competencies with appropriate participation is further complicated on high performance building projects because the competency requirements of the individuals involved in the design are different from those of a traditional building. High performance buildings require an even greater set of additive functional competencies than a traditional project, and thus place an even greater demand on the distribution of competencies among team members (Reed and Eisenberg, 2003). The more competencies an individual team possesses, the more likely the project will succeed (Riley, et al., 2004).

Systematic Competency Identification Method

Competencies are most often identified through a combination of “techniques” and “models” (Marrelli, 1998). Techniques include interviews, focus groups, surveys, and observations. Models include products or processes, job responsibilities and accountabilities, or differences between superior and other performers (Langdon and Marrelli, 2002). Competencies are also most often identified and associated with specific job descriptions within an organization, but in most cases this is not the purpose of the job description, and this process leads to inaccurate competency identification. In addition to the traditional job description method, current competency identification techniques include menus and databases, adopting models from other organizations, brainstorming, and comparisons of superior and other performers (Rothwell and Lindholm, 1999; Langdon and Marrelli, 2002).

For the purposes of this research, none of these techniques in and of themselves can adequately analyze the design process for high performance buildings and effectively identify the required competencies as well as The Language of Work Model. A more complete model of performance, known as the Language of Work (Langdon and Marrelli, 2002), can overcome the limitations of current competency identification techniques and place a greater emphasis on competency requirements of a job process. The Language of Work provides a basis for defining jobs (projects) so that we can then build a system for identifying competencies. Initially a job model is defined, competencies are then systematically built into the job model plus attributes, taking into account the knowledge and skills needed to perform the process steps, use the inputs, follow conditions, and use feedback. Then the necessary standards, work support, and the human relations needed to perform the job can be taken into account. A detailed list of steps to be performed in the Language of Work competency identification process is provided in Appendix B.

2.8 Summary

The current literature related to the main components of the present research have been discussed in this chapter. A discussion of widely accepted decision-making theories from the field of manufacturing and their relation to the research being conducted is provided. A thorough understanding of sustainable and high performance buildings and building design processes has been presented. The definition and differentiators of sustainable and high performance buildings have been provided to create a context within which the design process discussion for high performance buildings can take place. A review of accepted process modeling techniques for building design has also been presented, and the reason for selecting the technique used for this research has been explained. After the literature on decision making and decision-based design engineering, concurrent engineering, and lean production was reviewed, a basic understanding of each was presented to provide the fundamental theories upon which the case study propositions were developed. The final portion of the literature review provided information on existing individual and team competency identification techniques and describes a systematic methodology to identify individual and team competency requirements. Chapter 3 will build off of the information found during the literature review and present the research methods utilized in the research.

Chapter 3

Research Design Methodology

3.1 Introduction

This chapter describes the research methodology used throughout this study. The chapter is separated into three main components that explain the research process in chronological order. Section 3.2 presents the research process that provided the basis for a detailed case study development. This includes an overview of the relevant literature review and a detailed explanation and justification for the research techniques selected. Section 3.3 explains the case study research strategy, including a step-by-step description of the case study design. Section 3.4 describes limitations of the research based on the techniques selected and steps taken to minimize these limitations.

3.2 Research Process

The seven-step research process (Yin, 2003) used in this research is presented in Table 3-1**.** These steps included a review of the relevant literature and current building industry practices in building design (specifically high performance building design), theoretical model and evaluation process development, the selection of a research strategy, case study proposition development, case study data collection methods, case study data analysis techniques, and a statement of research limitations. The actions taken for each step are also shown with the location in this dissertation where the findings for each action are presented.

Table 3-1: Research Process (Yin, 2003)

Research Steps	Actions
Section 3.2	
1) Review Relevant Literature/Practices	- Conduct literature review (Chapter 2) - Collect and document professional practices (Chapter 2)
2) Model and Evaluation Process Development	- Develop a theoretical model – Design Decision Network Model (DDNM) (Chapter 1) - Develop a project-level model for high performance building projects – Design Process Model for High Performance Buildings (DPM^{HP}) (Chapter 7) - Apply the DPM^{HP} model and validated propositions findings into an industry implementation tool – Design Process Evaluation Model for High Performance Buildings ($DPEM^{HP}$) (Chapter 4)
3) Selection of Research Strategy	- Identify research type – Exploratory (Chapter 3) - Align main purpose of research with research type (Chapter 3) - Evaluate research technique (Chapter 3) - Determine research strategy - select multiple case study format (Chapter 3)
Section 3.3	
4) Case Study Proposition Development	- Determine proposition theoretical basis (Chapter 4) - Select units of analysis (Chapter 4) - Link data to propositions (Chapter 4) - Develop criteria for interpreting results (Chapter 4)
5) Collect Case Study Data	- Interview multiple project participants (Chapter 5) - Develop a case study database (Chapter 5) - Maintain a chain of evidence for all data collected (Chapter 5) - Evidence collection techniques (Chapter 5) o Documents o Archival records o Interviews o Direct observation o Physical artifacts
6) Analyze Case Study Evidence	- Perform event pattern matching (Chapter 6) - Analyze cross-case event synthesis (Chapter 6) - Utilize an explanation building approach to refine propositions (Chapter 6)
Section 3.4	
7) Research Method Limitations	- Identify research limitations (Chapter 3)

3.2.1 Review of Relevant Literature and Professional Practices

The initial step of the research process was to review the current design process management of information for sustainable and high performance design as reported in the literature and in current professional practices for building design. A brief overview follows.

Literature Review

An in-depth review of the existing literature describing the design process for buildings has been performed, with special consideration of the integrated design process for sustainable and high performance buildings. The relatively small amount of research that has been conducted in the building industry on design processes compared to the manufacturing industry led to an evaluation of theoretical design management research in other industries. Topics considered were lean manufacturing, concurrent engineering, options based theory, and decision-based design. This review combined with information gathered from meetings with practicing design experts in the field of high performance buildings provided the basis for the theoretical design model presented in Chapter 1.

Meeting of Design Experts - Integrated Design Roundtable

A roundtable meeting of key industry and academic professionals from the United States was assembled in Tarrytown, NY to identify current industry practices in the area of high performance building design. The group met to examine the definition and implementation of the integrated building design process. The goal of the meeting was to develop a shared understanding of the integrated design process and to produce a research agenda supporting a transformation of the building industry. Participants engaged in discussions concerning the barriers, key components, and core competencies of the process throughout project delivery. The roundtable discussion (see Figure 3-1) produced a map that assembled lessons learned from industry experts and provided an initial foundation for this research.

Figure 3-1: The First Integrated Design Roundtable, Tarrytown, NY

3.2.2 Design Process Evaluation Model Development

Three different models were developed in this research through a case study approach to address three distinctly different issues regarding the design process of the high performance buildings: (1) the Design Decision Network Model (DDNM), (2) the Design Process Model for High Performance Buildings (DPM^{HP}), and (3) the Design Process Evaluation Model for High Performance Buildings ($DPEM^{HP}$).

Design Decision Network Model (DDNM)

A necessary precursor to the Design Process Model for high performance buildings is the theoretical framework for the design process. It has been determined that a modified decision-based design environment is most representative of the building design process (Section 2.9). Chapter 1 explained in detail the reasoning behind the development of a theoretical DDNM for buildings as the basis for the research, and specifically that the design process consists of a network of information, decisions, analyses, commitments and competencies.

Design Process Model for High Performance Buildings (DPM^{HP})

Within the boundaries created in the DDNM$^{\mathrm{HP}}$ and informed by data collected from the case study projects, the DPM$^{\mathrm{HP}}$ was developed in the IDEF^0 modeling methodology to represent a project-level design process model for high performance buildings and to capture the design process information that was gathered during the review of current practices and literature as well as from case study findings. These models have aided in the case study proposition development, tested the DDNM by showing the process could be represented in the proven IDEF^0 modeling format, and provided an initial decision-based process model for the design of energy systems which can be utilized in design management and design process evaluation.

Design Process Evaluation Model for High Performance Buildings (DPEM^{HP})

Based on validated proposition findings and the previous two models that were developed as part of this research, the DPEM$^{\mathrm{HP}}$ provides a decision-based process/evaluation tool that outlines the steps that should be taken in the design of high performance buildings. This model organizes the evaluation process into a rational format to help project teams manage key decisions and analysis activities with regard to the information, competency requirements, and sequence of activities.

3.2.3 Selection of Research Strategy

Babbie (2004) identified three common purposes of social science research as exploration, description, and explanation. The main purposes of the study reported here were to investigate the poorly defined design process for high performance buildings, determine the impact of a process-based methodology to evaluate and manage the design process for high performance buildings, and to make recommendations for future research. As a result, this research has been classified as exploratory and qualitative in nature (see Table 3-2).

Table 3-2: Alignment of Research with Purposes of Exploratory Qualitative Research

Purposes of Exploratory Qualitative Research (Marshall and Rossman, 1989)	**Main Purposes of this Research**
Investigate poorly understood phenomena	Investigate the poorly defined design processes for high performance buildings
Identify/discover important variables	Identify key events in the design process for high performance buildings
Generate hypothesis for further research	Make recommendations for future research

An accurate characterization of the design process structure for high performance buildings and development of a design process evaluation model for high performance buildings was sought in this research. Qualitative social science practices have been utilized (in the form of proposition testing on multiple case studies) as a means to develop an evaluation method for the design process of high performance buildings. The identification of supporting case study events was used to validate the research propositions (section 3.3).

3.3 Case Study Research Strategy

The three research characteristics that help a researcher determine the use of a particular research strategy are (1) the type of research question posed, (2) the extent of control the researcher has over the events, and (3) the degree of focus on contemporary versus historical events (Yin, 2003). An analysis of the characteristics of this research project led to the selection of case studies largely because the research focuses on contemporary behavior and does not require or allow for control of behavioral events (see Table 3-3).

Table 3-3: Research Technique Evaluation

Strategy	**Form of Research Question**	**Requires Control of Behavioral Events?**	**Focuses on Contemporary Events?**
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival Analysis	Who, what, where, how many, how much?	No	Yes/No
History	How, why?	No	No
Case Study	How, why?	No	Yes

To ensure quality design in case study research, four widely used tests common to all social science case study methods were implemented: construct validity, internal validity, external validity, and reliability (Yin, 2003; Kidder and Judd, 1986). Table 3-4 summarizes the tactics employed in this research to assure that the four common tests of quality were met, as described below.

Construct Validity: establishing correct operational measures for the concepts being studied (Yin, 2003). The degree to which a measure relates to other variables as expected within a system of theoretical relationships (Babbie, 2003). Construct validity can be assured by collecting data from multiple sources (Yin, 2003).

Internal Validity: “(used only in explanatory case studies) establishing a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships” (Viking, 1999).

External Validity: the generalizations of findings to or across target populations (Pedhazur & Schmelkin, 1991). The first requirement of external validity is internal validity.

Reliability: demonstrating that the study can be replicated.

Table 3-4: Case Study Tactics Employed to Assure Quality Research

Test	**Tactic Suggested by Yin, (2003)**	**Tactic Implemented in this Research**	**Phase of Research in Which Tactic Occurs (Yin, 2003)**
Construct Validity	• Use of multiple sources of evidence	• Data triangulation through multiple point sources including interviews of multiple project participants on the same project or interviews and independent source evidence on the same project • Data triangulation through multiple events	• Data collection
	• Establish chain of evidence	• Create a research design process model for each step of the case study data collection	• Data collection
	• Have key informants review draft case study report	• Solicit comments on final process models from industry participants	• Composition
Internal Validity	• Pattern matching	• Identify multiple similar guiding events of key design process implementation and improvement	• Data analysis
External Validity	• Use replication logic in multiple case studies	• Collect data to investigate multiple projects designing high performance buildings	• Research design
Reliability	• Use case study protocol	• Standard protocol for conducting case study interviews and a guide for the final report has been developed (Appendix D)	• Data collection
	• Develop case study database	• Event tracking for each proposition (Appendix D)	• Data collection

A small number of case studies (three) of building design projects were considered so that an in-depth knowledge of the design process for energy systems (the main component of High Performance Buildings) would be understood for each project. The expectation with this aproach was that some similarities and contradictions between projects would be realized, either confirming or contradicting the research propostions.

3.3.1 High Performance Building Case Study Proposition Approach

The complete research design in case study research embodies a “theory” of what is being studied (Yin, 2003). The theory that was investigated in this research was the development of a competency and process-based methodology to evaluate the design process for high performance buildings that could minimize waste and improve design team performance. To investigate this theory, six propositions were developed to guide the case study research that would provide direction as to which data to collect and the strategies for analyzing the data collected.

In the traditional approach to case study research, the development of propositions directs attention to the issues that should be examined within the scope of the study and that serve as the basis for analysis in the research. In this research, testing the propositions simultaneously acts as an evaluation approach in addition to focusing the attention to the issues of importance. Validation of each proposition confirms an accurate characterization of an aspect of the design process for high performance buildings as set forth in the proposition. This accurate characterization in turn identifies key areas to be considered during the design process for high performance buildings. The six propositions used for this study are stated below. (A detailed description of each proposition, their role in the design process evaluation model and the corresponding theory that served as the basis for each proposition are provided in Chapter 4.)

Proposition #1 – Building Function*:* Engineering the design process based on the building project’s desired functions will add value to the design process.

Proposition #2 – Design Decision Network*:* The design process is a network of decisions producing commitments, connected by discipline-specific analysis activities performed by design actors with associated competencies.

Proposition #3 – Decision Timing & Sequencing*:* Changes to the sequencing and timing of key decisions, dictated by the building's desired functions, can add value to the overall design process.

Proposition #4 – Pull-Driven Information*:* Value is added to the design process when critical decisions that need to be made pull the information and analyses required to reach an informed commitment.

Proposition #5 – Competency-Based Value*:* Effective implementation of the integrated design process is dependent upon inclusion of key individual and team competencies.

Proposition #6 – Decision-Based Evaluation Model*:* A process-based methodology to assess sequencing and timing of key decisions in the design process results in an improved design process based on value added/value lost.

3.3.2 Case Study Units of Analysis

The experimental case study design technique requires the development of strategies for executing scientific inquiry to enable the researcher to make observations and interpret the results. Accurate establishment of an effective unit of analysis is critically important in any case study research (Fellows and Liu, 2003). To establish the unit of analysis studied in an effective manner, the initial question that served as the basis for this research is revisited:

> *Does the development of a process-based and competency-driven methodology to evaluate the design process for high performance buildings eliminate waste and improve the decision-making capabilities of the design team?*

A project-level analysis was performed on high performance buildings through a case study research approach to answer this research question. Specific project events constituted the main unit of data collection, and an evaluation of the competency and process-based methodology and its impact on the decision-making capabilities of the team was measured through pattern matching to the research propositions. A project-level analysis was chosen over other units that were considered, including industry and organization level analysis for the following.

The focus of the research on high performance buildings dictated the need to evaluate the process at a more detailed project level than at a broad organizational or industry level. Focusing on project-level cases throughout the industry afforded the researcher the opportunity to focus on explicit attributes of the design process for high performance buildings. Utilization of multiple organizations as sources of evidence helped to construct validity that would not have been achievable if the research had only been conducted for only one organization.

In addition, competency requirements of design professionals at an industry or organizational level could not be defined at the level of detail required for this research. Proposition #1 states, the building design process should be engineered to a particular end by the building's desired functions. Competency requirements would vary depending on the building's desired function. An industry or organizational analysis could discover general competency requirements for design. However, detailed competency identification specific to high performance buildings required a project-level analysis unachievable at the industry level. An organizational unit of analysis could be utilized for competency identification; however, only high performance building projects could be considered. Therefore, approaching this portion of the research at an organizational level would unnecessarily limit the results to one organization, decreasing the overall research validity.

The final consideration when selecting high performance projects as the units of analysis was the additional importance of an integrated design process for these buildings. Cross-disciplinary collaboration becomes increasingly important due to the heightened emphasis on design minimization and the elimination of associated redundancies that accompany a segregated linear approach. An integrated design approach strives to involve the appropriate professionals throughout the design process, simultaneously eliminating the segregation of disciplines. To consider an entire industry or an organization would introduce projects that do not place the same emphasis on cross-disciplinary collaboration, resulting in additional variables for consideration.

3.3.3 Case Study Data Link to Propositions – Cross-Case Synthesis and Event/Proposition Pattern Matching

A multiple case design was used to discover confirmative examples of each of the propositions set forth. Replication or direct contrast of the stated proposition would be viewed as confirmation of acceptable data collected for each proposition. This section explains the criteria selected for data collection and the evaluation technique that was used in this research to link each kind of data to the corresponding proposition.

Case study data collection evaluation focused on the identification of events contained attributes related to the propositions developed. An *event* is defined as a design process attribute or action taken by the design team or a team member that impacts the design process in measurable changes in value or waste in the design process. Given the integrative nature of the high performance design process, an emphasis was placed on investigating design interventions and cross-disciplinary interactions when identifying potential case study events.

Project attributes and actions taken by actors throughout the design process were measured for the value or waste that was introduced to the process through these events. The definitions of value and non-value-adding actions for this research were as follows:

Value-adding action: Activity that efficiently converts information towards that which is required for a design inclusive of the desired building functions.

Non-value-adding (wasteful) action: Activity that takes time and/or resources but does not add relative worth or importance to the process.

As part of this research, greater level of definition was developed for types of value and waste exhibited in the design process to allow measurement of case study events. These are presented in Figure 3-2.

Proposition support by an event is defined as one that positively or negatively reflects the given proposition. *Positive support* maintains the proposition as stated through direct conformity, resulting in at least one identifiable stated proposition outcome. *Negative support* maintains the proposition through non-compliance with a particular proposition statement that resulted in process waste. Events that *contradict* a proposition would also be reported and considered in the final proposition validation evaluation. *Contradiction* is defined as a rival event that disproves the proposition.

Propositions #1, #3, #4, #5, and #6 explain attributes of the design process that result in value generation through compliance or the introduction of process waste through non-compliance. For these propositions, events determined to support a proposition positively had to (1) include all main components of the proposition and (2) clearly exhibit a value type to the process, as defined in Figure 3-2. Events that negatively support a proposition had to (1) include contradicting main components of the proposition and (2) clearly exhibit a negative value result or a waste type as defined in Figure 3-2.

1) *Process Cost* ***Value*** – actions, attributes, decisions, or commitments that improve the design/construction process through cost reduction

2) *Process Time* ***Value*** – actions, attributes, decisions, or commitments that improve the design/construction process through duration reduction

3) *Process Sequence* ***Value*** – actions, attributes, decisions, or commitments that improve the design/construction process through organization of design activities

4) *Individual/Team Competency* ***Value*** – skills and knowledge possessed by individuals or the team resulting in beneficial information generation, decision making, or commitments

5) *Decision Timing* ***Value*** – the balance between ambiguity and commitment when considering the timing of a decision resulting in an optimum commitment

6) *Process Commitment* ***Value*** – binding to a course of action by an individual or team that generates information that correctly informs and supports future decisions.

7) *Information* ***Value*** – positive knowledge acquired through study, experience, or analysis introduced to a decision

8) *Sustainability* ***Value*** - actions, attributes, decisions, or commitments that improve the design/construction process through improved safety, health, or energy efficiency

9) *Rework* ***Waste*** – the process of performing work activities multiple times with no identifiable value added

Figure 3-2: Value and Waste Definitions

3.3.4 Criteria for Interpreting Results

Each of the six propositions was evaluated independently of the others with the main components of the proposition being given special consideration. A methodical event analysis approach was developed and implemented. Figure 3-3 represents the methodology followed for each potential event evaluation.

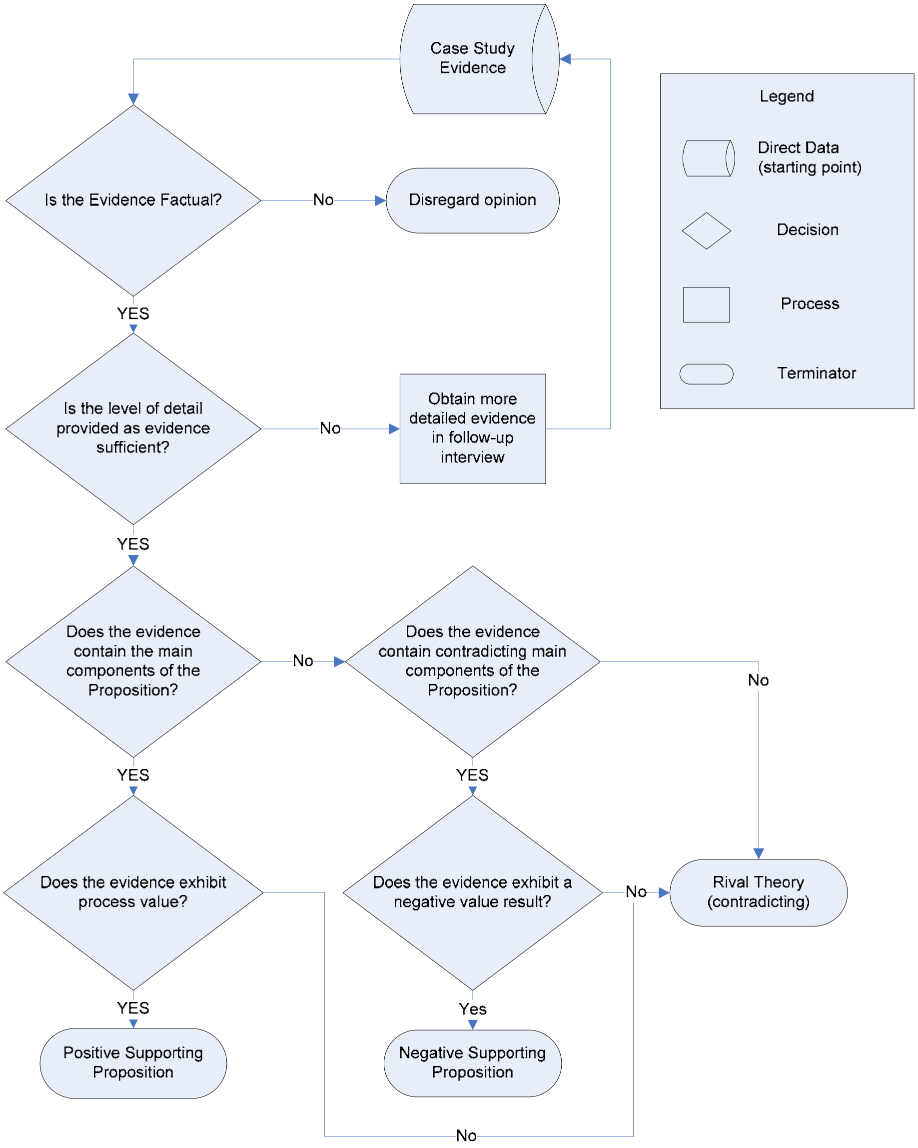


Figure 3-3: Proposition Event Evaluation Flow Chart

Key considerations in the evaluation of potential events included the factuality of the event, the level of detail provided, and inclusion of individual proposition main components. The main components of each proposition are listed in Table 3-5.

Table 3-5: Proposition Main Components

Proposition #1 – Engineering the design process based on the building's desired functions will add value to the design process.	Identification of the building and project's desired function Identification of the design process plan
Proposition #2 - The design process is a network of decisions producing commitments, connected by discipline-specific analysis activities performed by design actors with associated competencies.	Identification of key commitments in the design process Identification of information required to complete the design Identification of analyses that were performed during design Identification of decisions that were made in the process Identification of competencies of the individuals and team conducting the design
Proposition #3 - Changes to the sequencing and timing of key decisions, dictated by the building's desired functions, can add value to the overall design process.	Identification of a key decision Identification of the timing of the decision An evaluation of the timing of the decision resulting in a value impact
Proposition #4 - Value is added to the design process when critical decisions that need to be made pull the information and analyses required in order to reach an informed commitment.	Identification of a critical decision Identification of information developed to inform the critical decision Identification of waste or value that was added during the decision
Proposition #5 - Effective implementation of the integrated design process is dependent upon inclusion of key individual and team competencies.	Identification of a specific individual or team competency that was either present or missing during the design Identification of the impact of the competency on the execution of the desired design activity
Proposition #6 - A process-based methodology to assess sequencing and timing of key decisions in the design process results in an improved design process based on value added/value lost.	A specific planning action during the design of the building that focused on mapping the design process in a measurable manner

3.3.5 Case Study Data Collection

The three principles of data collection for conducting case study research are (1) to use multiple sources of evidence, (2) to create a case study database, and (3) to maintain a chain of evidence. These principles are adhered to in this research, and the results are data that reflect construct validity and reliability.

Yin (2003) identified six potential sources of evidence for case studies: documents, archival records, interviews, direct observation, participant observation, and physical artifacts. The three case studies conducted for this study all emphasized interviews more than any other source. As Table 3-6 shows, all three case studies (American Indian Housing Initiative - AIHI, School of Architecture and Landscape Architecture - SALA, Cambria Building - Cambria) also used at least two other sources of information.

Table 3-6: Sources of Evidence by Case Study

Case	**Documents**	**Archived Records**	**Interviews**	**Direct Observation**	**Participant Observation**	**Physical Artifacts**
AIHI	No	Yes	Yes	Yes	No	No
SALA	Yes	Yes	Yes	No	Yes	No
Cambria	Yes	Yes	Yes	No	No	No

Use Multiple Sources of Evidence – Each case study involved at least an interview with the design manager, architect of record, and mechanical engineer. By interviewing several individuals for each case, similar data were collected that could be compared, leading to more convincing and accurate information. Each data event was reviewed specifically for internal case corroboration in order to confirm the same fact or phenomenon. Figure 3-4 graphically represents the requirement for internal corroboration of an individual event, a minimum of *two sources* describing the *same event* in the same manner.

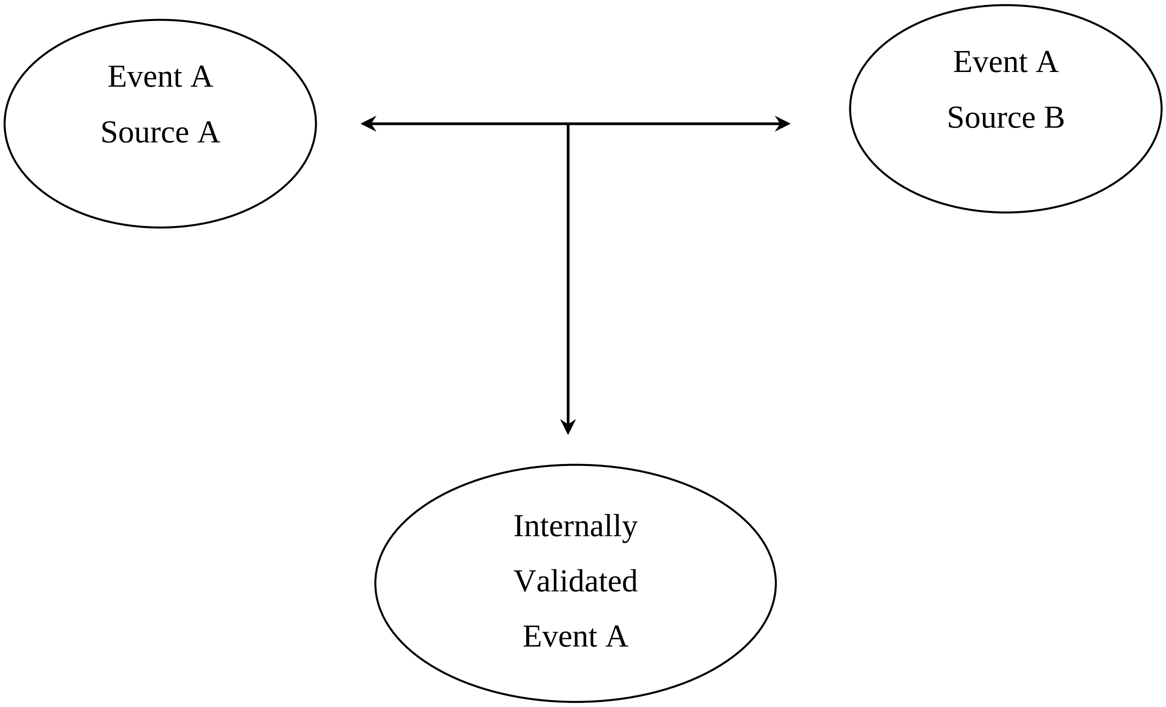


Figure 3-4: Internal Event Validation

In addition to internal case corroboration, each proposition sought cross-case event corroboration in the form of multiple internally validated event identification. The greater number of events identified as supporting a proposition improved the likelihood of its validation (section 3.3.3 discusses the required number of event replications for validation of each proposition). Figure 3-5 graphically represents the requirement for triangulation of an individual proposition. In order to attain proposition validation, the number of *internally validated events* identified through case study data collection, must be greater than the number of *internally validated event replications* (IVER's) required for proposition validation, as determined in Section 3.3.6 (Table 3-7).

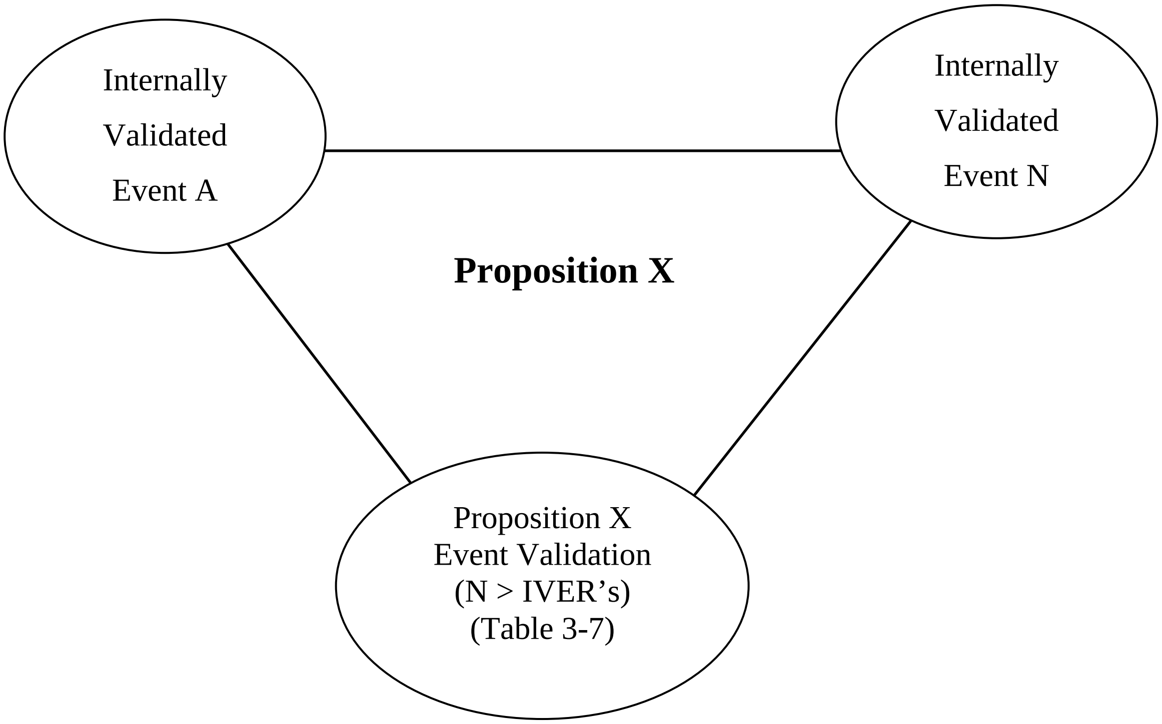


Figure 3-5: Proposition Event Validation

Create a Case Study Database – Each interviewee received a letter of introduction via email that provided a general overview of the research being conducted in preparation for the interview (Appendix D.1). As the interviews were conducted, they were digitally recorded, and the audio recordings were stored in the case study computer database. The recordings were then reviewed by the researcher within twenty-four hours, and pertinent information was extracted and recorded in written form on an interview tracking form (Appendix D). The tracking form was then reviewed, and events that potentially supported or contradicted any of the propositions were identified and recorded in the event tracking forms (Appendices E, F and G). After the event tracking forms were completed, they were forwarded to each interviewee, and an informal follow-up conversation was held to further clarify the information discussed as well as to gain any new, relevant information.

Maintain a Chain of Evidence – Five key components of the research and their clearly identified relationships provided the chain of evidence in the research. These components included the case study questions (Appendix D), case study protocol (Appendix D), citations of specific events to the case study interview database, case study database consisting of interview recordings, interview tracking form and event tracking sheets, and the final case study-informed, cumulative proposition event tracking tables (Appendices E, F and G).

3.3.6 Analyzing the Case Study Evidence

Each case study consisted of a “whole” study, in which convergent evidence was sought regarding the facts and conclusions for the case through event support for each proposition. After the case study data were collected through multiple interviews, potential event alignment with the six research propositions was evaluated for cross-case synthesis and replication, determining matching patterns between cases. Replication for this research was defined as multiple, *internally validated event replications* (IVER’s) (within individual cases or across cases) that support the proposition positively or negatively. The number of replications required for validation of each proposition varies, depending on the criteria established for significance (much as is the case when choosing p values in statistical research). Criteria for significance included researcher discretion, judgmental choice, and the desired certainty of the research findings (Yin, 2003).

Specific consideration was given by the researcher to the two determining factors of desired replication quantities when determining the number of literal event replications required for proposition validation. These were the level of desired certainty in each proposition and the degree of difference in rival theories. Different levels of each determining factor were established to determine the required number of replications for proposition validation. Table 3-7 provides a summary of each proposition and the number of replications required for proposition validation and the rating level for each determining factor. A description of the rating levels for each determining factor follows.

Table 3-7: Event Replication Requirements for Proposition Validation (Adapted from Yin (2003))

Proposition	**Internally Validated Event Replications Required (IVER's)**	**Level of Desired Certainty (High, Medium, or Low)**	**Level of Difference in Rival Theories (Great or Little)**
1	3	Low	Little
2	4	Medium	Little
3	5	High	Little
4	5	Medium	Great
5	6	High	Great
6	4	Medium	Little

Level of Desired Certainty

Each proposition contained different levels of detail and in turn resulted in different levels of desired certainty. The desired certainty categorization was divided into three levels for this research: low, medium, and high. The propositions that addressed specific design process phenomena and in turn contained the highest level of detail received a high rating. An example is Proposition #5. Specific competencies, which were the focal point of this proposition, resulted in a detailed component of the design process, i.e., individual and team competencies. This high level of detail in this proposition resulted in a desire for heightened certainty and the resultant high rating.

Propositions that addressed a broad or more general aspect of the design process were expected to contain lower levels of detail and receive a low rating. Proposition #1 is the only proposition that received a low rating for this research. It addressed the structure of the design process and its relationship with the desired functions of the project. No specific activities, decisions, or competencies were directly addressed in this proposition, which made it more general than the others, and which led to a low level of desired certainty rating.

For the propositions that addressed both general process issues at a more detailed level, a medium rating was assigned. Propositions #2, 4, and 5 all received a medium rating. Each contained a detailed process component with examples, including key decision identification, the timing of those decisions, and the information required to make decisions. All three also addressed the design process at a more global level. The combination of these two attributes led to the assignment of a medium level of desired certainty for these three propositions.

Level of Difference in Rival Theories

In addition to desired certainty, rival theories were considered when determining the levels of event replication required for proposition validation. A rival theory is one that is different from the original theory stated in the proposition under consideration. Each proposition was analyzed for the level of difference compared to rival theories. A binomial value of ‘little’ or ‘great’ was assigned to each proposition. The propositions that were considerably different than a rival theory received a great rating. Propositions #4 and #5 both received ‘great’ ratings. Rival theories that were exceptionally drastic existed for both of these propositions. Proposition #4 was based on the pull-driven theory professed in lean manufacturing. While widely accepted in lean manufacturing, this approach to information generation has a strong opposition theory in the form of push-driven management.

Pull, by its simplest definition, means that no one upstream should produce a good or service until the costumer downstream asks for it (Womak and Jones, 1996). In push-driven management, activities are expected to start as early as possible (Tommelein, 1998). The direct contradiction in theories is obvious, and when considered in this research for Proposition #4, led to a great rating for level of difference in rival theory. The propositions that had subtle differences compared to rival theories receive a rating of little.

Proposition Validation Requirements

The propositions that had exceptionally different rival theories and demanded low levels of certainty required the least number of replications. For this research–based on examples provided by Yin (2003), the validation requirement was determined to be three replications for the propositions exhibiting these two characteristics: For each increase in level of desired certainty, an additional event was required for validation. The same held true for the propositions that had little difference from rival theories. For example, if a proposition was found to have a medium level of desired certainty and showed a great difference from rival theories, four replications were required for event validation. If the rival theory difference was found to be little, an additional event replication was sought for validation. For this research, four replications were required for a proposition that had little difference from its rival theories and required low levels of desired certainty.

3.4 Research Method Limitations

Researcher Bias

The main limitation to conducting interview-based case study research is the bias of the researcher. Bias is “a tendency to observe the phenomenon in a manner that differs from the ‘true’ observation in some consistent fashion” (Simon and Burstein, 1985). Researcher bias was considered in both the data collection phase of the research as well as in the data interpretation process. During the data collection process, bias was avoided by developing a rigorous interview protocol as described in Section 3.3.2. After the interviews were completed, the results were forwarded to each interviewee for review and confirmation of fact.

During the data analysis phase, bias was addressed and minimized by evaluating the information in a systematic manner. A content analysis (as described in Section 3.3.2) of the data from each interview provided an accurate description of the relevant events as described in the interview.

Limited Number of Case Studies as Validation

This research addressed the emerging field of high performance design. As an emerging field, the number of applicable case study projects that are available to the research team is currently limited. However, a design process database is currently being developed in conjunction with the Department of Energy and the Design Build Institute of America that will allow future studies to be conducted on design process and competency requirements of the high performance design process.

Because this research was exploratory and sought to characterize more accurately a phenomenon in building design process, statistical significance was not sought. Therefore, the limited number of cases made available for this research was not as significant as would be the case in a statistical study using sampling logic as its research basis. The development of this exploratory research will aid the implementation of appropriate research into the field of high performance design process in the future. Chapter 4 will present the proposed design process evaluation model for high performance buildings and the relationship of the propositions developed for the research to each step in the model.

Chapter 4

Case Study Proposition Development

4.1 Introduction

An objective in this research is to provide a methodology to improve continuously value in the design process of high performance buildings through reductions in design process waste. To achieve this objective, improvements in relationships, timing, and sequencing of design decisions as well as the competencies available to make these decisions have been evaluated for their contribution to added or lost value in the design process. A proposition-based case study approach was used to aid in the Design Process Evaluation Model (DPEM) development to achieve this goal. This chapter presents the theories and provides guiding examples that were used as the basis of the propositions that were developed in this study as well as the design evaluation model that has been tested. Each proposition is presented and described in detail.

4.2 Synthesis of Research Findings: Design Process Evaluation Model for High Performance Buildings (DPEM^{HP})

The design of high performance buildings requires a heightened integration of team members. Through proposition validation, this research aims to characterize the design process accurately and show that there are key attributes of the design process for high performance buildings that add value. A descriptive process model that presents the findings of the research will help to reduce the negative impact associated with the education and learning that is required of new design teams at project conception. The model considers the effective integration of participant involvement using information dependency in the design process as an organizing guide and provides a mechanism by which building project teams can evaluate alignment between the high performance design process and the key competencies required throughout the process.

The Design Process Evaluation Model for High Performance Buildings (DPEM^{HP}) contains steps that guide the team in the identification of the key decisions, information requirements and sequencing during the design process. The model organizes the evaluation process into a rational set of steps so that the project team can make key decisions in an effective manner with regard to information and competency requirements and sequence of activities. The basis of this model is the findings of the proposition development and testing conducted in the research. It should be noted that the model as a unit was not tested or validated in this research. The steps and the information and tools that can aid in each step of the DPEM^{HP} are presented in Table 4-1.

Table 4-1: Design Process Evaluation Model for High Performance Buildings (DPEM^{HP})

DPEM^{HP} Action	Research Support
Step #1) Determine building's desired function & form team	Energy System Competency Identification (Table 7-1)
Step #2) Develop decision based design model	Level II DDNM^{HP} (Figures 7-3, 7-4, and 7-5)
Step #3) Evaluate key decisions for value added based on timing and sequencing	Value definition system (Figure 3-2)
Step #4) Identify information considerations needed for key decisions	Level II DDNM^{HP} (Figures 7-3, 7-4, and 7-5)^{P}
Step #5) Identify competency requirements for process implementation	Energy System Competency Identification (Table 7-1)

The DPEM^{HP} and corresponding research propositions are shown in Figure 4-1. The model represents each step as part of a cyclical evaluation process, aiming to continuously improve the design of the building through an improved design process.

The initial step in the design of any building is the assembling of a team. The team can be as simple as a master builder acting as the designer and constructor contracted to a building owner or as complicated as a design-build project employing a developer hired by the leaser to form a team of designers, contractors and suppliers looking to build a space to be occupied by a third party. No matter what the team format is, the core competency requirements of the team members participating in the design of a high performance building must be considered. The once the team is assembled, the building's desired function shall be determined. This determination is important because it will aid in step two of the DPEM^{HP}.

The second step that should be undertaken by the design team is development of a decision based design process map. A planning session to develop a design process model including key design team participants was effectively implemented on the AIHI case study in the late stages of design. It was determined that earlier execution of this activity would have been beneficial to the project. Validation of Proposition #1 will demonstrate that the functions of the building project plays a vital role in the development of the design process. Because high performance buildings place a heightened importance on the building's energy performance and the air quality of the building, the design process should place greater emphasis on decisions impacting each of these building attributes. The DDNM^{HP} provides an initial model for design teams to utilize when developing the design process model for their project.

Once the decision-based design process model is developed, key decisions should be evaluated based on their timing in the overall process as well as the sequence in which they are organized (step three). This is an activity that should continue throughout the design process aiming for continuous improvement of the overall process. If validated, Proposition #3 will demonstrate that changes to sequencing and timing of decisions have a measurable impact on the design process in the form of value or waste added. Each decision in the process model should be evaluated for the types of value that are most important to the design team. Those value types presented in this research can act as guidance in the development of an appropriate value and waste attribute list for any project type. Decisions that are determined to be inappropriately sequenced or timed should be moved within the design process.

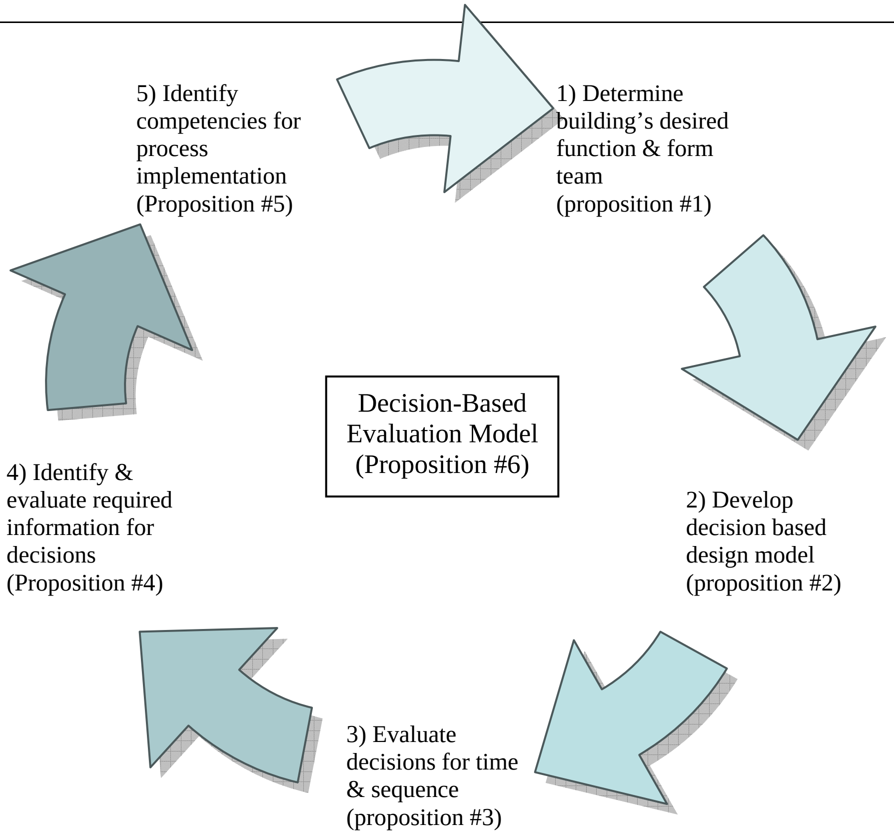


Figure 4-1: DPEM^{HP} Process Evaluation

After the design process has been modeled and key decisions analyzed for appropriate timing and sequencing, the information that is required to make informed decisions should be determined (Step #4). If validated, Proposition #4 will demonstrate that pulling the information required to make key decisions adds value to the overall design process. Once the information needed to make key decisions is identified, the final step of one evaluation cycle of the DPEM^{HP} should ensue.

Each decision and analysis should be evaluated for critical individual competencies required to effectively make a decision and reach a commitment (Step #5). A systematic competency identification technique should be utilized for identifying desired competencies to carry out the design effectively. Regardless of the final set of competencies identified, an analysis of the design team should be conducted and individuals identified who possess the specific competencies required to inform and make each key decision effectively. If the team is lacking a desired competency it should be added either through new actor introduction or the education of an existing actor. As the process model is evaluated throughout the design and team changes take place, the competencies possessed by the design team should be evaluated.

The DPEM^{HP} presents the research findings in an applicable format that can be utilized in industry practice. The validation of the research propositions will show that the individual attributes of the DPEM^{HP}, when conducted in an appropriate manner, result in a design process that has increased value over one that does not.

4.3 Case Study Propositions

Six propositions were developed to derive the critical attributes of design process management evaluation from the case study data collected for this study. Each proposition originated from an examination of the building design literature and examples of industry practices during the review phase of this research.

Guiding examples of design practices in industry were considered to inform the development of each proposition. The six propositions and the corresponding theory on which they were based are provided in Table 4-1. A description of the guiding examples from the review of industry practices and a description of the propositions derived from the examples follow the table.

Table 4-2: Case Study Propositions and Theory

Proposition	Theoretical Basis
1) Building Function: Engineering the design process based on the building's desired functions will add value to the design process.	Lean Production – identifying value dictates process (Womack and Jones, 1996)
2) Design-Decision Network: The design process is a network of decisions producing commitments, connected by discipline specific analysis activities performed by design actors with associated competencies.	Decision-Based Design – "design decisions are based on information obtained from a variety of sources, going well beyond the engineering disciplines" (Hazelrigg, 1998)
3) Decision Timing & Sequencing: Changes to the sequencing and timing of key decisions, dictated by the building's desired functions, can add/detract value to/from the overall design process.	Design Decision Network Model (DDNM) Integrated Functional Design (Evbuomwan and Anuba, 1998)
4) Pull-Driven Information: Value is added to the design process when critical decisions that need to be made pull the information and analyses required to reach an informed commitment.	Lean Production – pull-driven processes (Womak and Jones, 1996)
5) Competency-Based Value: Effective implementation of the integrated design process is dependent upon inclusion of key individual and team competencies.	Team Selection – "teams should be determined by the skills needed to accomplish the work" (Luecke, 2004)
6) Decision-Based Evaluation Model: A process-based methodology to assess sequencing and timing of key decisions in the design process results in an improved design process based on value added/value lost.	Lean Production – continuous value enhancement through process management and improvement (Liker, 2004)

4.3.1 Basis for Proposition #1 - Guiding Example of Building Function: Prison Design Process

A large contractor, ranked the third largest contractor in the United States in 2005 by *Engineering News Record* (Tulacz, 2005), is currently the lead design-builder on three major prison projects in Virginia. One in South Hampton County involves prison renovation for the addition of 600 new beds. The other two projects, in Pittsylvania County, Virginia, and Tazewell County, Virginia, are for the new construction of eight buildings with 1,024 beds each. Each of these two prison construction projects includes four housing buildings, one administration building, a support building that contains visitation areas, gymnasiums, vocation and teaching areas, and medical facilities. Each prison development is to be completed with a warehouse and a gatehouse.

During design, the design-build manager for the projects identified a noticeable difference in the design process for these structures compared to the design process for a typical office building. Strong emphasis was placed on the necessity to create safe and lockable spaces in the buildings to keep the inmates contained and the prison guards safe. This single main focus drove the construction and design process and resulting in different decisions emphasized during the design process than would be the case for a different building type. Ceiling configurations and details received greater attention and detail early in design because of the potential for escape at these locations. Security not only for partitions and ceilings, but for doors, frames and hardware drove the design process.

The same impact a desired building function plays on the design process can be seen on hospital and semi-conductor plants. On a hospital project an entirely different set of desired functions are elevated in priority. The inclusion of complicated medical gas distribution and supply systems lead to extreme piping and mechanical coordination requirements early in the design. Semi-conductor plant designs are driven by the specification requirements of the chips that will be made in the building. This specification dictates the allowable floor vibrations based on tolerances of the chips to be fabricated. This results in a design process that cannot proceed with structural systems design until the chip specification is finalized.

4.3.2 Research Proposition #1 - Function-Based Process Design:

> **Engineering the design process based on the desired functions of the building will add value to the design process.**

The functional needs of a completed building differ for all projects. The identification and prioritization of these needs play a major role in the development of an appropriate building design process. The needs identified as valuable to the final building design dictate the timing and sequencing of key decisions to be made during the design process. Appropriate alignment of the building's desired functions with the building design process will result in added value; conversely, their misalignment will lead to lost value or waste. If validated, Proposition #1 provides the basis for the notion that it is possible to define a generalized process (in the form of a basic design model) for buildings that have the same desired functions.

4.3.3 Basis for Proposition #2 - Guiding Example of Decision-Based Design: Manufacturing Industry

Viewing the design process for high performance buildings as a network of interdependent decisions provides the opportunity to define an under-described environment in a manner that facilitates the evaluation and assessment of the overall design process. Chapter 1 illustrated the impact of making decisions at three distinct times at a conceptual level.

Decision based design is a widely accepted approach in the field of manufacturing. As presented in Chapter 2 numerous models exist that characterize the manufacturing design process with decisions as the focal point. Pugh, Shooter, Suh and Hollins have all represented the manufacturing design process in terms of decisions. It is these models that serve as the basis for the development of Proposition #2. The existing manufacturing decision based design models are unable to accommodate all facets of the design process for buildings; therefore a modified modeling approach has been developed and presented in Chapter 1. Proposition #2 incorporates all of the attributes of the Design Decision Network Modeling technique that was presented in Chapter 1.

4.3.4 Research Proposition #2 – Design Decision Characteristics:

> **The design process is a network of decisions, producing commitments that are connected by discipline-specific analysis activities and information, each performed by design actors with associated competencies.**

The design process is characterized as a network of decisions in a sequence connected by analyses activities, each performed by design actors (individuals that participate in the design process). As decisions are made, commitments are introduced that provide certainty for subsequent decisions. Four different kinds of design activities have been derived from similar classifications introduced by Bretschneider (1993). This classification of design activities was used in the characterization and interpretation of case studies in this research as well as in the development of the DDNM^{HP}:

- Information – knowledge acquired through analysis or experience
- Commitment – obligation or responsibility for a future design action
- Decision – accepting or rejecting a proposed design action
- Analysis – checking the effects that proposed design actions have on the building project

Significant decisions can be broken down into the following sequence: those that define systems (schematic), materials (design development), and construction details (construction documents). Examples of decision making include evaluation of design options, shared knowledge between disciplines, and the subsequent determination of a design decision, such as the style of mechanical system, or the type of glazing for a building.

During periods between design decisions, analysis activities are performed and information is produced. Examples of analyses in any design process are computer simulations, code reviews, cost estimates, design aesthetic precedents, and material research. As certainty and information are produced by decisions and analysis, respectively, new information is created for future decisions in the design process. Prerequisite to commitments and analysis results, information is the key enabler of the decision-making processes throughout the design.

In addition to the four different kinds of design activities, the parties responsible for performing the design have been characterized as actors possessing specific knowledge, skills, and traits required to effectively complete the design. Both decisions and analyses are performed by design actors and require different kinds of expertise that can be defined as specific competencies. Accordingly, ‘actors’ are individuals who participate in the design process, and competencies are an underlying characteristic of an actor (i.e., motive, trait, skill, knowledge) that produce effective and/or superior performance on a job.

Actors participating in the design process include owners, engineers, architects, contractors, and suppliers, to name a few. Examples of competencies required for design include consensus building skills, design management and analysis skills—including energy modeling expertise—and the ability to interpret analysis data.

4.3.5 Basis for Proposition #3 - Guiding Example: Mis-timed Energy Simulations

Guidance for the development of Proposition #3 originated from an initial review of the findings from a case study report by DeWilde (2004) that addressed the computational tools used during the design of the Netherlands Energy Research Foundation Building (ECN). The building in this project was constructed to host additional office and laboratory space for the organization. According to the ECN’s mission, the new building should contribute to a clean and reliable energy supply for a viable world. The building is roughly 30,000 ft^2, and construction was completed in 2001. Incorporation of energy-savings components was a key desired attribute of the final building design.

A specific problem regarding the timing of the use of the computational tools was found on the project. Energy modeling was performed only during the preliminary and final phases of design, as well as for the preparation of building specifications and construction documents. However, De Wilde witnessed no use of computational tools during the conceptual phase of the design. The computer models were developed only for verification of selected components at this time.

If the computational energy modeling tools had been utilized during the conceptual phase of the design improvements for the ECN building, the final design could have been realized through reduced energy consumption.

4.3.6 Research Proposition #3 – Decision Timing and Sequencing:

> **Changes to the sequencing and timing of key decisions, dictated by the building's desired functions, can add/detract value in the overall design process.**

The appropriate sequencing and timing of certain key decisions dictated by the intended functions of the building adds value to the overall design process. Tension exists between ambiguity about design development and the need for commitments. This tension can be alleviated by examining the way future designers are educated. Universities and professional architecture organizations currently instruct architects to delay decisions as long as possible in hopes of discovering an optimal solution. At the same time, engineers are taught to solve problems with the information provided so that decisions can be reached and commitments made so that the "next step" of a design can proceed. In most cases, the optimum solution to this problem from an overall process perspective lies somewhere in between each of these scenarios.

Decisions that are made too early (Value of Ambiguity is greater than the Value of Commitment; VoA > VoC) or too late (VoA < VoC) generate waste in the process decreasing the net process value. When decisions are committed to at an appropriate time (VoA = VoC), overall process value is increased. Changes to the sequence or timing of key decisions will change the amount of net process value. The preferred decision is the option whose expectation balances the value of ambiguity and commitment resulting in the highest process value. A desired competency of the design team is the ability to optimize process value through the effective balance of commitment and ambiguity.

4.3.7 Basis for Proposition #4 – Guiding Example of Building Envelope Definition – The Pennsylvania State University School of Architecture and Landscape Architecture

During the planning phase for a 145,000 square foot classroom building designed and constructed on the campus of Penn State University, a team charette was conducted to develop team goals and produce a schematic vision for the facility. Achieving a LEED^{TM} Siler rating had been identified as a primary goal, with an emphasis on energy consumption reduction. In the charette, the lead mechanical engineer led the discussion for the building's schematic vision.

It was determined by the team that the key decision that needed to be made in the meeting was the building's orientation and configuration. A heightened importance is placed on these attributes in energy efficient buildings because the operating performance is significantly impacted by the way the building interacts with the solar patterns of the region. The information that was required in order to reach an informed decision was the site solar attributes, surrounding environment, overall site constraints, and anticipated energy system performance. Once this information was identified as required to inform the building orientation and configuration decisions, it was pulled from the charette participants and a schematic vision created for the building shape and orientation. This vision ultimately became the final building design.

4.3.8 Research Proposition #4 – Pull-Driven Commitments:

> **Value is added to the design process when critical decisions that need to be made *pull* the information and analyses required to reach an informed commitment.**

When viewed as a network of decisions-produced commitments, connected by discipline-specific analysis activities, each performed by design actors with associated competencies, each component of the design process becomes easily measurable. The decisions that produce commitments are informed by analysis results. In many cases, the information that is made available for any given decision dictates what the decision is and when it is made. A more effective way to view the design process is to view decisions as driving forces that pull information from the actors involved in the design process. When this is accomplished, value will be added and a more efficient design process realized.

4.3.9 Basis for Proposition #5 - Guiding Example of Design-Build Mechanical Systems

The competitive advantages of design-build mechanical contractors that make value-added contributions to high performance building projects through appropriate competency involvement have been identified through case study research conducted by Riley, et al. (2005). The integrated design and detailed approach implemented on a health care facility in California illustrates first cost savings as well as the value generation from the constructability competency possessed by the mechanical contractor that was used during design.

Significant sources of waste in the design-bid-build process for mechanical systems were the redundancies in the development of engineering design documents required for bidding, and in the subsequent shop and fabrication drawings produced by the mechanical contractor. On this health facility project, scaled engineering drawings were produced by the mechanical contractor’s detailers who incorporated fabrication and constructability information during the early stages of design documentation. As a result, construction costs could be minimized while opportunities for prefabrication were maximized. On the project evaluated, the final mechanical system design was priced at 13% first-cost savings over the original system developed for the owner by a consulting engineer. In addition, the system efficiency exceeded the requirements of California’s Title 24 Energy Incentive Program, resulting in a rebate of $40,000 to the owner. This illustrates that the inclusion of key competencies possessed by the design-build mechanical contractor added value to the overall design process.

4.3.10 Research Proposition #5 – Competency-Centered Team:

> **Realization of value generation from implementation of the improved design process is dependent upon inclusion of key individual and team competencies.**

Effective process and operations management depends on team make-up and the inclusion of the required skills to carry out the plan successfully. Rather than measuring the skills desired of a given title (i.e., architect, engineer, contractor, etc.), the focus must be on the desired competencies of individuals who make up the team as well as cross-functional competencies of the team. The effective implementation of the improved design process developed in Proposition #3 is dependent upon the inclusion of key individual and team competencies.

4.3.11 Basis for Proposition #6 - Guiding Example of North American Lexus Headquarter Renovation Project

A three-story, 60,000 square-foot office building was constructed by Toyota North America for its Lexus headquarters in 2005. The project included lobby renovations, atrium work, vehicle display areas, and energy efficient lighting features, as well as HVAC retrofits. A desired primary function of the project was image enhancement, that is, to align the building appearance with the Lexus automobile image. During this project, the entire facility project process was researched and a detailed map developed (Lapinski, 2005).

A comparative analysis between the project process and the Toyota Real Estate and Facilities (RE & F) project process was conducted; the results of this insightful analysis demonstrated that significant differences between the two had caused waste. For example, the Lexus project was placed on hold until the fiscal year 2003, resulting in supplementary rework and the lack of execution of an early phase of the RE & F process. Development of the model enabled these two conditions to be immediately recognized and provided a visual connection of the downstream effects of these two problems. According to the research team, it would have taken numerous meetings for these problems to surface. The analysis also determined that without the map and the comparative analysis capabilities it presented, the problems might not have surfaced at all.

4.3.12 Research Proposition #6 – Decision-Based Evaluation Model:

> **A process-based methodology to assess sequencing and timing of key decisions in the design process results in an improved design process based on value added/value lost.**

A critical component of the definition phase of the design process is prioritization of design decisions. Desired building functions aid in this process (Proposition #1). The development of design decision sequence and methodology to ascertain the appropriate sequence and timing of the process will create increased value. Mapping the process allows the opportunity not only to manage the process more efficiently, but also to evaluate the decisions sequence and related costs of the process prior to implementation. In addition to added value, development of a methodology to assess the sequencing of key decisions also provides a structured vehicle to reduce waste within the process by providing parameters and the associated deadlines within which design teams can operate.

4.4 Summary

A research methodology that uses a proposition-based case study approach was developed, and specific building industry examples that served as the basis for the propositions developed in the research have been presented. These propositions, when considered together, serve as the basis of the Design Process Evaluation Model (DPEM). Each guiding example and a description of the propositions have been presented in this chapter. In Chapter 5 the techniques utilized in the research to test each proposition are presented, and the case study projects that have been investigated are introduced.

Chapter 5

Data Collection and Testing

5.1 Case Study Data Collection Project Summaries

The design process was analyzed on three recently completed contemporary buildings to study the network of decisions, information, analyses, and competenceis required to complete the design process. Note that a study of the *entire* design process of these cases in general was not an objective as this would have made the scope of the work unnecessarily broad and time-consuming. Instead a focus was placed on the energy system (all systems that impact the final energy performance of the building, e.g. building mechancial, electrical, lgihting systems and building envelope systems) design decision process due to the heightened importance and integral part energy-saving systems have in the high performance building design process.

During the review of literature for this research, the energy systems design were determined to be the main aspect of the design process for high performance buildings that differentiates it from the design process for high performance buildings. Two key attributes of the design process for high performance buildings were identified to heighten the role of energy systems design in the overall process when compared to that of a non-high performance building process. These elements are (1) a complex relationship between energy systems and all other building systems during the design process due to a heightened emphasis on systems integration in search of energy performance optimization and (2) the continuous role energy systems design has throughout the entire design process on high perfoemance buildings. Because the energy systems design is what seperates the high performance design process from a non high performance design process, the research focused on the decisions, commitments, information, analyses and competencies utilized in the energy systems design and the results are expandable to high performance buildings.

Accordingly, the objectives of the case study investigations in this research were to:

1. Develop a decision-based process model to assess the sequencing of key decisions in the design process of the energy systems of a high performance building (Proposition #6),
2. Test Propositions #1-#6 for validity, and
3. Collect industry data to inform the development of a practical guideline for high performance building design evaluation and management.

After studying the cases separately, a cross-case analysis was carried out to provide a detailed view of the design process for energy systems design and to test the research propositions for validation (see Chapter 7).

The cases were selected for investigation based on the following requirements:

1. The emphasis placed on the attainment of an energy-efficient building (must exceed ASHRAE 90.1 at minimum by 40%),
2. The inclusion of projects representing a range of project type, size, and delivery systems, and
3. The willingness and accessibility of design team members to participate in the research project, in particular those involved with the mechanical and energy systems design.

Each case study included an interview with the project owner/occupant representative, architect, mechanical engineer, and other participants who had a significant impact on the energy system design. At least four individuals were interviewed from each project, and design documents or project reports were reviewed for all of the projects. The general design processes for the following buildings and the detailed processes for their energy systems design have been analyzed:

1. The Pennsylvania Department of Environmental Protection Cambria Office Building,
2. The Pennsylvania State University School of Architecture and Landscape Architecture (SALA) Building, and
3. The American Indian Housing Initiative (AIHI) Early Childhood Learning Center.

Each case was conducted and analyzed using the following approach.

Data Gathering

Phase one consisted of collecting relevant information about the case. Literature concerning the case was reviewed. Participating companies, key actors within these companies, their disciplines, and the teams and structures in which they operated were identified. Special attention was paid to events related to the research propositions and interdisciplinary interaction during the design process. Finally, the most important participants in the energy systems design process were interviewed. The interviews focused on the decisions, commitments, information, and analyses that constituted the design process. The interview question guidelines can be found in Appendix B. The interviews were conducted by the researcher in accordance with the general guidelines for interviews as described by Babbie (2004). Every interview was audio recorded in a digital format and reviewed by the researcher for content.

Content Discovery

Phase two included discovery of the pertinent information that was collected in the interviews and a review of the documents. Each audio-taped interview was transcribed by the author to identify project events that are related to the research propositions. The transcribed data were reviewed and potential events identified and recorded in an event tracking table with all of the events being listed in Appendices E, F, G and H. Each potential event was reviewed for conformance with the requirements of the proposition, and follow-up conversations were conducted with the interviewees if additional information was required. Once an event was identified, it was analyzed and a determination made whether it supported the proposition. The results of the individual events as confirmed can be found in Table 5-1.

Table 5-1: Event Tracking Summary

	Cambria		**SALA**		**AIHI**	
	Potential Events Recorded	**Confirmed Events Recorded**	**Potential Events Recorded**	**Confirmed Events Recorded**	**Potential Events Recorded**	**Confirmed Events Recorded**
Proposition #1 *Function-Based Process Design*	10	10	6	4	4	4
Proposition #2 *Design Decision Characteristics*	5	3	3	1	3	1
Proposition #3 *Decision Timing & Sequencing*	17	15	17	17	13	13
Proposition #4 *Pull-Driven Commitments*	14	11	10	8	6	11
Proposition #5 *Competency-Centered Team*	29	22	16	15	16	16
Proposition #6 *Decision-Based Evaluation Model*	0	0	0	0	2	2

Event/Proposition Support Analysis

The third phase of the case study research included an independent analysis of each event for its support of the assigned proposition. An event could either support the given proposition in a positive or negative manner, or contradict the proposition. *Positive support* maintained the proposition as stated through direct conformity, resulting in at least one identifiable value-added, stated outcome of the given proposition. *Negative support* maintained the proposition through non-compliance of the proposition that resulted in process waste. *Contradiction* is defined as a rival event that does not support the proposition. The results of the positive and negative support for each project and proposition can be found in table 5-2.

Table 5-2: Event Proposition Support

	Cambria		**SALA**		**AIHI**	
	Positive Support	**Negative Support**	**Positive Support**	**Negative Support**	**Positive Support**	**Negative Support**
Proposition #1 *Function-Based Process Design*	9	1	3	1	4	0
Proposition #2 *Design Decision Characteristics*	3	0	1	0	1	0
Proposition #3 *Decision Timing & Sequencing*	12	3	3	14	3	10
Proposition #4 *Pull-Driven Commitments*	8	3	5	3	3	8
Proposition #5 *Competency-Centered Team*	20	2	10	5	8	8
Proposition #6 *Decision-Based Evaluation Model*	0	0	0	0	0	2

Individual Case Event Triangulation

Each event that was determined to support a given proposition was compared to other events within the individual case study for replication. Replicated event occurrences that supported a proposition were identified and an internal case study proposition validation was identified for each project. A summary of the individual case study event proposition findings can be found in Sections 5.2.1 through 5.2.6.

Cross-Case Analysis

The analysis of individual cases was followed by a cross-case analysis. Here the occurrence of similar triangulated events in each project was studied to determine the degree of proposition support within and between cases. A detailed description of the cross-case analysis and results can be found in Chapter 6.

5.1.1 Case Study #1 – Pennsylvania Department of Environmental Protection DEP Cambria Office Building

- Owner/Occupant Representative: Department of Environmental Protection
- Architect: Kulp Boecker Architects, P.C.
- Mechanical Engineer: Phoenix GeoThermal Services
- Energy Modelling/Consulting: Energy Opportunities, Inc.

The first case study project investigated in this research was a 34,500-foot office building primarily housig the Commonwealth of Pennsylvania's Department of Environmental Protection (DEP) management and field personel. The building construction was completed in the fall of 2000 with design activites begun in 1997. For this building, the DEP integrated high-performance building features into its design process from the beginning to meet its goal of producing a high-performance, environmentally friendly building. Among the high performance features chosen for the building were efficient wall and roof insulation, high performance windows, ground source heat pumps, an underfloor distribution system (UFAD), energy recovery ventilators (ERVs), daylighting, motion sensors, and an 18.2 KW photovoltaic (PV) system for on-site electricity production (Deru, et al., 2005).

The final building design achieved a LEED^{TM} 2.0 Gold Certification from the U.S. Green Building Council (USGBC, 2005). The design of the building includes anticipated energy performance that exceeds by 60% the industry standards set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2001). The project team was assembled by the project developer in conjunction with the leasor, the Department of Environmental Protection (EPA). A design-build delivery method was utilized on the project.

5.1.2 Case Study #2 – The Pennsylvania State University School of Architecture and Landscape Architecture (SALA) Classroom and Office Building

- Owner/Occupant Representative: The Pennsylvania State Unviersity Office of Physical Plant
- Architect Joint Venture: WTW Architects and Overland Partners
- Concept/Schematic Mechanical Engineer: Ove Arup & Partners Consulting Engineers P.C.
- Post Schematic Mechanical Engineer: H. F. Lenz Company

The second case study project investigated in this research was a four-story building that houses the Architecture and Landscape Architecture Departments at The Pennsylvania State University. The 145,000-square foot building is primarily comprised of design studios, faculty and administrative offices, a library, computer lab, and workshops. The building construction was completed in the summer of 2005 with design activiites beginning in 2001. A sustainable design charette was conducted at the beginning of the project in part to focus the efforts of all team members on reducing the final energy consumption of the building. Among the high performance features chosen throughout the design process for the building were efficient wall and roof insulation, high performance windows, daylighting controls, an underfloor distribution system (UFAD), heating, ventilation and air-conditioning (HVAC) heat recovery system, and building system-controlled operable windows.

The final building design aims to achieve a LEED^{TM} 2.0 Gold Certification from the U.S. Green Building Council (USGBC, 2005). The design of the building includes an anticipated energy performance that exceeds by 40% the industry standards set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2001). The project team was assembled by the building owner. A construction management delivery method was utilized on the project.

5.1.3 Case Study #3 – The American Indian Housing Initiative (AIHI) Early Childhood Learning Center (AIHI)

- Owner/Occupant Representative: Chief Dull Knife College and the Department of Architectural Engineering at The Pennsylvania State University
- Architect Joint Venture: Department of Architecture, University of Washington and The Pennsylvania State University
- Mechanical Engineer: Energy A.D., Billings MT.

The third case study project investigated in this research was an Early Childhood Learning Center (ECLC). The building is a 4,800 square foot facility built for Chief Dull Knife College in Lame Deer, Montana. The building construction is scheduled to be completed in the summer of 2006 with design activities begun in 2004. Built with strawbale construction and structural insulated panels, the ECLC has numerous healthy and energy efficiency design features, including daylighting, radiant floor heating, evaporative coiling, and sustainable materials.

The final building design aims to achieve a LEED^{TM} (Leadership in Energy and Environmental Design) 2.1 Gold Certification from the U.S. Green Building Council (USGBC, 2005). The design of the building includes anticipated energy performance that exceeds by 40% the industry standards set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2001). The project team was assembled by the building owner’s representative. The organizational structure and composition of the project team are unique because there are no contracts between the building owner and the primary design members. The majority of the work was accomplished on a volunteer basis except for sitework, utilities, mechanical, electrical and plumbing systems, and some finishes. The design team primarily consists of faculty and graduate students from the architecture, architectural engineering, and landscape architecture degree programs.

5.2 Case Study Data Testing

A total of 153 supporting events were found for the six propositions tested in the research. Events were analyzed for internal validity within the case study context through verification represented by direct repetition with one other project source. A total of 35 events in the six propositions were found to be repetitive within a case study. A summary of the event validation within each case study is found in Table 5-3. Because Proposition #2 event identification is determined by the ability to model a process in the context developed in the DDNM, triangulation was measured by the ability to model the process, not by the decision, information, commitments, and competency making up the model.

Table 5-3: Case Study Proposition Internal Verification

	Cambria		**SALA**		**AIHI**	
	Supporting Events	**Validated Events**	**Supporting Events**	**Validated Events**	**Supporting Events**	**Validated Events**
Proposition #1 *Function-Based Process Design*	10	3	4	2	4	2
Proposition #2 *Design Decision Characteristics*	3	3	1	0	1	1
Proposition #3 *Decision Timing & Sequencing*	15	4	17	2	13	3
Proposition #4 *Pull-Driven Commitments*	11	3	8	2	11	1
Proposition #5 *Competency-Centered Team*	22	3	15	3	16	2
Proposition #6 *Decision-Based Evaluation Model*	0	0	0	0	2	0

A summary of the findings for each case organized by proposition is presented in the following sections, and a detailed record of all events for all three case studies can be found in Appendices E, F, G and H. Included below is a detailed description of the event categories that occurred most often for each project presented by proposition.

5.2.1 Proposition #1 – Function-Based Process Design

Department of Environmental Protection Cambria Office Building event categories represented:

- Advance the concept of high performance green buidlings
- Reduce energy consumption
- Augment indoor air quality
- Develop sustainable building within the confines of conventional cost

Reduce Energy Consumption Example

The reduction of energy consumption was a clear goal of the Cambria project. The owner’s representative, architect, and mechanical engineer all expressed the importance of reduced energy consumption in the final building design. All three specifically noted the impact this desired building function had on the design process itself. The utilization of an integrated design approach was necessary to minimize energy consumption and to construct the facility at conventional building costs.

In addition to reducing energy consumption, a major desired function of the Cambria Building was the advancement of the concept of high performance green buildings. This was to be achieved by providing a comfortable and productive work environment while minimizing its environmental impact. The team committed to a LEED^{TM} Gold rating on the project during the definition phase of the design process and established performance targets required to achieve this rating. The definition phase of the project focused on integration of disciplines when developing the building orientation, form, and function requirements as dictated by LEED^{TM}.

A benefit of the integrated design approach was the reduced mechanical load requirements through the reduction of the building’s loads. The following excerpt is from the interview with the project’s mechanical engineer.

> “Typically a building like this from an air-conditioning standpoint would have more than enough capacity. Every safety factor is included in every calculation and the result would be somewhere between 350-400 sf/ton. That is pretty standard in classic design schemes. The desire to minimize energy use and loads led to an understanding of the how the building was being used. This is a building for field engineers that 4 out of 5 days of the week were going to be in the field. This allowed the design team to take some liberties in anticipated occupancies that normally wouldn’t be taken. The owner’s representative, who understood the usage of this building, was able to convey the intended use with a certainty that allowed the design team to push the limits of design loads. The final design ended up with somewhere near 650 sf/ton, which is considerably less capacity than a building of this size and type would normally have. The benefits were a significant reduction in the size of the entire mechanical system, including the (ground source heat pump) loop field; so, it paid off in reducing its own cost and probably pays off in performance in the long run as well. Other design measures that impacted the way we developed the final building design included all team members’ focus on the development of an appropriate light shelf design, the wall construction, and location of equipment.”

The desire to reduce energy consumption directly impacted the design process as early as the negotiations of the lease and design. The team developed a list of very specific attributes the project needed to meet from design, performance, and operations standpoints. This list of attributes resulted in performance requirements for the building that could not be met through conventional design techniques. The performance standards generated the need for an integrated design process that focused on cross-disciplinary optimization. The form (configuration and orientation) of the building was clearly driven by the need to accommodate daylighting in the design and to reduce energy consumption through reduced building loads. Integration of the design process accomplished by design members all focusing on the optimization of systems made this desired project function attainable.

The Pennsylvania State University School of Architecture and Landscape Architecure Classroom and Office Building event categories represented:

- Advance the concept of high performance green buildings
- Reduce energy consumption
- Act as a visual advertisement for the departments that occupy

Reduce Energy Consumption Example

As was the case with all three case study projects, a premium was placed on achieving a low-energy performance building that utilized sustainable systems while providing comfort to the building occupants. This emphasis resulted in the recognition of a heightened importance of interdisciplinary design team coordination. A specific example as told by the conceptual phase mechanical engineer follows.

> "The conceptual design team's simultaneous utilization of computer models for daylighting and energy consumption analysis came about because of the heightened importance of energy consumption reduction when developing the design. The mechanical, electrical and plumbing designers evaluated the daylighting study and computer models together during concept design, and studied each system with the architecture in an effort to develop the optimum energy efficient design concept through effective utilization of daylighting. Specific items that were looked at included location of daylight sensors, different shading options for glazing, and solar paneling, and how much light gets into the building."

The desire to reduce energy consumption also led the owner to develop a unique design team organization. An internationally renowned architect and engineer were hired for the definition phase of the project. Each possessed specific sustainable and energy-efficient design expertise as well as energy modeling capabilities in-house.

American Indian Housing Initiative Early Childhood Learning Center event categories represented:

- Reduce energy consumption
- Design for constructability (to accommodate volunteer labor)

Reduce Energy Consumption Example

A premium was placed on a healthy and energy-efficient building design. Material choices considered the environmental impact, taking the greatest advantage of the resources available in the region, and so the final building design consumed less energy than set forth by code. To accomplish this primary building function, the emphasis during the definition phase of the project was on building footprint and building envelope selection so that energy-efficient design decisions could be made after appropriate analyses.

The mechanical engineer stated from a mechanical design process perspective that involvment early in the design process during the building envelope development is desired when energy consumption reduction is desired. AIHI made a conscious effort to solicit input from the mechanical designers during the definition phase of the project as well as energy model development at the same time to inform all design decisions. Decisions focused on the simplicity of mechanical systems during selection in order to control cost and to allow for appropriate controls for the mechanical systems, aiming to keep things simple while making sure there was no opportunity for competition between the heating and cooling systems that would create energy system waste.

5.2.2 Proposition #2 – Design Decision Characteristics

All three of the case study projects were analyzed for the applicability of a decision-based design process network as an accurate means to characterize the design process. Accurate characterization required represntation of the design process in terms of decisoins, information, commitments, competenices, and analysees. Design process models were developed for the energy systems design utilizing the Design Decision Network Modelling methodology for all three projects. A resultant energy systems design process model (Design Process Model for High Performance Buidlings) developed as part of this research and supported from the case study findings is presented and discussed in detail in Chapter 7. A model from one indidividual on each project is presented in Figures 5-1, 5-2 and 5-3 (all project models develoed from the case study interviews can be found in Appendix I).

Department of Environmental Protection Cambria Office Building example of the Design Decisions Network Model for Energy Systems Design:

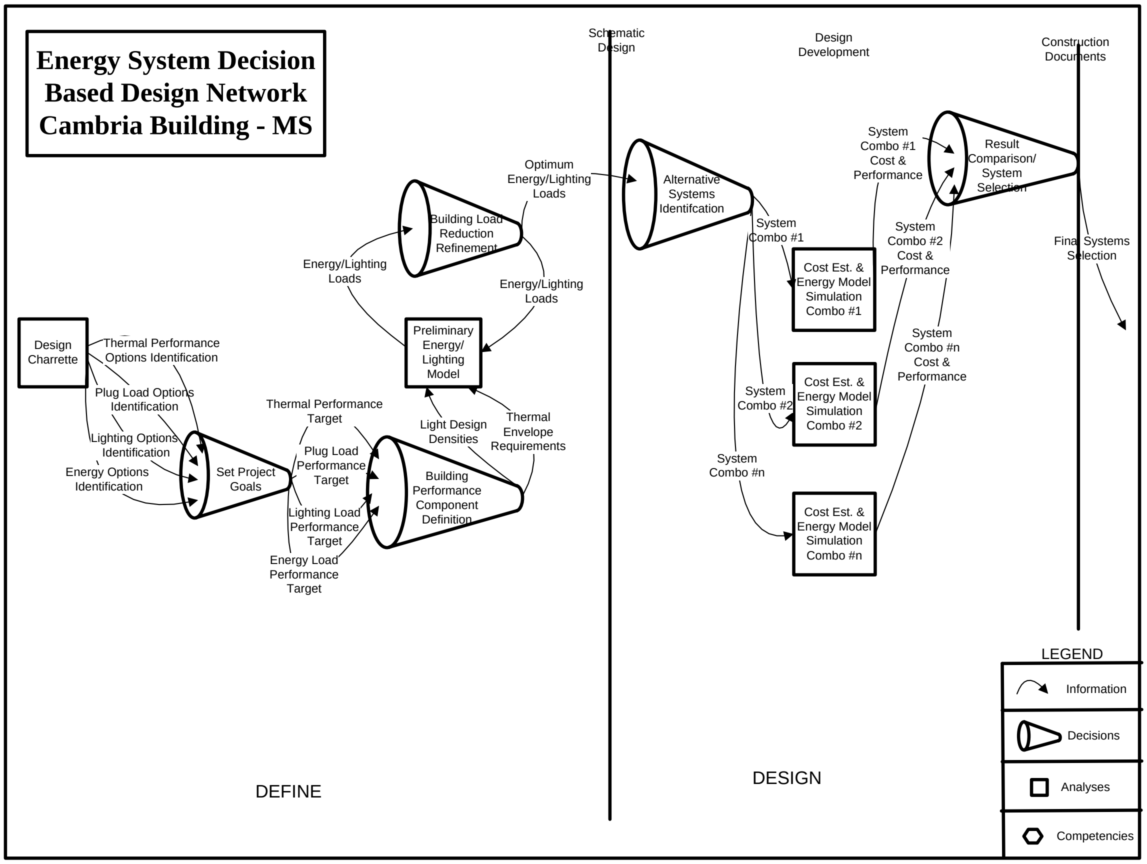


Figure 5-1: Design Decision Network Model for Energy Systems – Cambria Building MS

The Pennsylvania State University School of Architecture and Landscape Architecure Classroom and Office Building example of the Design Decisions Network Model for Energy Systems Design:

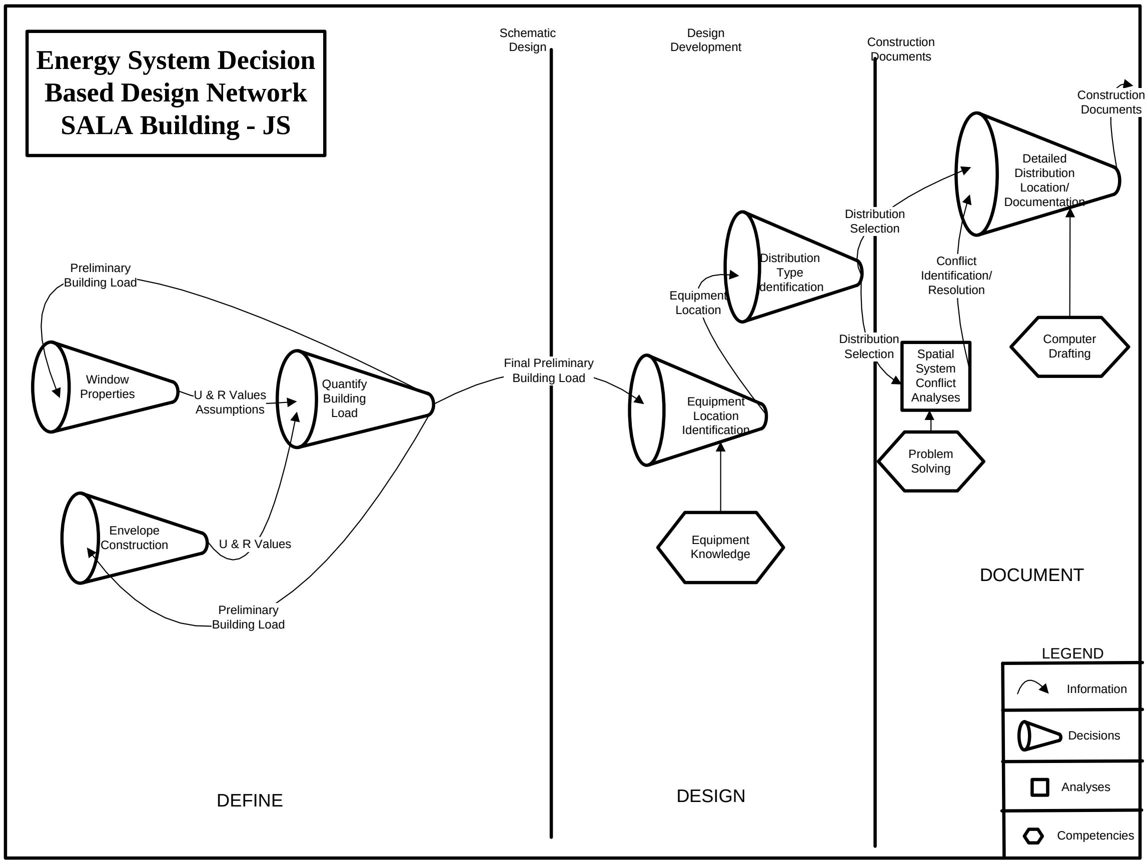


Figure 5-2: Design Decision Network Model for Energy Systems – SALA JS

American Indian Housing Initiative Early Childhood Learning Center example of the Design Decisions Network Model for Energy Systems Design:

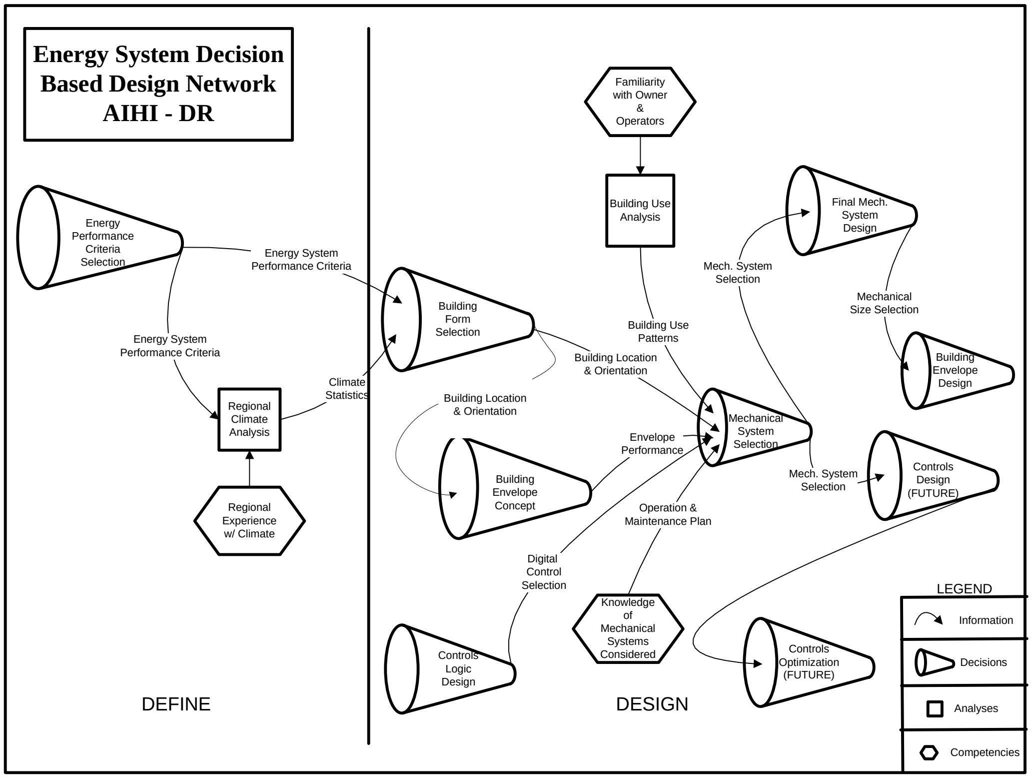


Figure 5-3: Design Decision Network Model for Energy Systems – AIHI DR

5.2.3 Proposition #3 – Decision Timing and Sequencing

Department of Environmental Protection Cambria Office Building event categories represented:

- Building configuration determination
- Building orientation determination
- Anticipated building energy load identification
- Building systems parameter tests

Building Configuration Determination Example

The very form of the DEP Cambria Building was driven by the need to maintain a proper orientation for daylighting, energy consumption, and maintenance of existing wetlands related to the project goal of minimizing site disturbance. This orientation and the site location of the building are not divorced from the configuration of the building. The final shape is a fairly long linear building on an east-west axis so that its aspect ratio of east-west to north-south is fairly low. There are much longer north-south elevations with virtually no fenestration on the east-west axis. This shape was developed in the definition phase of the project (early schematic) after a ‘square box’ had been initially presented. Shortly after this decision had been made, a fundamental layout was developed that runs through all of the enclosed private offices in the interior of the building down to the core so that 90% of the employees have access to daylighting in larger open areas.

In addition to the location of the building offices, one meeting was remembered by all of the design participants interviewed. During the design phase of the project, there was a struggle with where to place the mechanical equipment room—traditionally an architect designs the building and the mechanical engineer is asked to fit the equipment into the room. It was determined that this approach was not going to create an acceptable design (and still achieve desired energy savings at conventional costs). The architect asked the mechanical engineer where the mechanical room should be placed to optimize the energy systems. He picked some prime real estate in the building (first floor core). This is ultimately where the room was located in the final design with additional square footage added to both ends of the building to compensate for lost leasable space, all at a decreased first-time cost compared to the original design concept.

The Pennsylvania State University School of Architecture and Landscape Architecure Classroom and Office Building event categories represented:

- Building systems equipment selection
- Design team formation
- Design change notification
- Building configuration determination

Design Team Formation Example

The SALA project implemented a unique design team organization throughout the project. Initially a joint-venture architecture team was selected consisting of a nationally acclaimed sustainable architect teamed with a regional design firm. Once the architects were selected, a conceptual phase mechanical, electrical, and structural engineering firm possessing substantial sustainable design experience was hired to develop the building concept and begin the building design. The same arrangement took place with the landscape architecture firm. After the concepts had been developed for these systems, regional specialists were hired to replace the national designers. The timing of decisions as they relate to the team formation had a great impact on the value and waste that were introduced to the overall design process.

The transition of design responsibilities by the mechanical engineering firms was limited to two meetings and a design report summarizing the results of work completed to date. A specific problem was encountered because the new designer was brought on too late relative to the completion of the conceptual design for the appropriate design of an energy recovery system. The concept mechancial engineer did not include any energy recovery in the intial concept. During design development, the succeeding mechanical engineer determined that it would be worth considering in a green building; however, at this time, it was determined that no further action would be taken regarding this issue. With the building about 75-80% complete, the energy modeler ran another model and determined that the project could save money by including energy recovery. Space was needed to add pumps and coils, which caused much design rework, because the decision was made too late in the design process. It should have occurred earlier in the design process because of the heightened importance placed on energy savings in the beginning and the desire to pursue LEED^{TM} energy points. It impacted both by causing additional cost and time.

American Indian Housing Initiative Early Childhood Learning Center event categories represented:

- Building functional defintion development
- Design documentation
- Building systems equipment selection

Building Systems Equipment Selection Example

The heightened desire to produce an energy-efficient building placed the selection of energy system components under close scrutiny on the AIHI project. The timing of several systems was found to be effective and added value to the overall process while others were mis-timed and introducing waste. The energy-saving systems for the building were radiant floor heating and evaporative cooling. After recognizing the advantages of their use in the region, it was determined that previous decisions regarding related building systems didn not add the same value. Fortunately, the radiant floor heating and evaporative cooling were incorporated into the building late in the design process without introducing waste.

The project manager suggested a modified approach that would eliminate the risk of designing a building that could not accommodate the preferred natural mechanical system, one that would allow the building to form around the energy systems.

An Automated Logic controls system for the energy systems was selected by volunteers (engineering students) prior to the completion of the mechanical design. After the mechanical system was designed, it was determined that the Automated Logic system was inappropriate, because it could not be serviced by anyone within a 600-mile radius of the site. Due to time constraints, the design needed to be subcontracted to a local professional, causing rework as well as a missed opportunity to utilize cost-effective volunteer support.

5.2.4 Proposition #4 – Pull-Driven Commitments

Department of Environmental Protection Cambria Office Building event categories represented:

- Building configuration determination
- Buidling orientation determination
- Energy load determination/minimization
- Buidling functional defintion development
- Design documentation
- Material selection

Building Configuration Determination Example

The desire to design an energy-efficient DEP building not only impacted the design process, but also the information that was developed in order to inform decisions that had the greatest impact on the energy performance. The building configuration and orientation are extremely critical with respect to the building’s energy performance. The information required to make orientation/configuration decisions include a site plan with true solar North, an understanding of the functional program so that the configuration, orientation, and functionality all work together. Additional important information to achieve systems integration opportunities includes preliminary energy models with assumptions for u and r-values walls, roofs, and windows that accurately represent the performance of future material selections. This was either already available or requested and presented prior to determining the final building orientation and configuration. A series of refinements followed in an effort to engage as many strategies as possible to reduce the loads on the building.

Those instances when information was made available because decisions dictated their need resulted in a pull-driven approach. The approach resulted in an appropriately configured and oriented building with a design that anticipated energy savings 50% above ASHRAE 90.1 standards. Having the information available to base the design on enabled a thorough exploration of design opportunities, resulting in an energy-efficient final design.

The Pennsylvania State University School of Architecture and Landscape Architecure Classroom and Office Building event categories represented:

- Energy load determination/minimization
- Building dystems equipment selection
- Design team formation

Building Systems Equipment Selection Example

The SALA project building systems equipment selection pulled desired information on multiple occasions to inform decisions appropriately. The selection of energy-efficient systems depended on building properties and building use. Information that was required and provided to inform decisions included schedules of operation, occupant times for all spaces, building components from a fabric performance perspective, glazing types, wall types, building mass, building orientation, and envelope properties. Building use and properties were made available to the mechanical designer in a timely manner allowing for the completion of a building design that would achieve a 40% energy savings above ASHRAE 90.1. The inclusion of raised-floor distribution systems greatly contributed to this success.

The selection of areas to receive under-floor air distribution systems was based on information produced in a benefit-cost analysis of the raised floor by intended space use.

This information determined the selection of the studio spaces for under-floor distribution because these spaces needed to be flexible and easily reconfigured many times over the lifetime of the building. To design a flexible space cost effectively, it was determined that power and data connections to work stations need to be easily relocated. The raised-floor system allowed for this to be done with a plug-and-play system. Because flexibility is a requirement of the space, and a raised-floor system is the most efficient way to achieve this in the studios, a significant premium was not being paid for the HVAC under-floor distribution system. The studios were ultimately designed to trap hot air high and allow the cold air to stratify down low, creating an energy-efficient and more comfortable air distribution system. The key information provided by the benefit-cost analysis allowed this decision to be made effectively.

American Indian Housing Initiative Early Childhood Learning Center event categories represented:

- Building systems equipment selection
- Material selection

Material Selection Example

Selection of environmentally friendly materials (desired building function utilization of material resources that minimize environmental impact) was critical during the design of the AIHI building. Suitable materials were identified through designers' attendance at the USGBC Greenbuild 2004 Exhibition. A compilation of the identified materials was used to develop a kit of materials to be considered during the design, in lieu of force-fitting materials into the building to achieve the desired LEED^{TM} Gold Rating. Not included in the kit was a custom translucent exterior wall desired by the project architect.

Timely information was not provided for the translucent building envelope design, resulting in delays in the energy modeling and façade detailing. Due to the missing alternative translucent envelope material properties and resulting insulating performance ratings, the impact was costly, because skilled labor was required to install the systems as time was not available to plan for a volunteer installation. Besides the added cost, there was potential for the building performance to be impacted because the delay forced a misinformed decision (due to missing daylighting/energy analyses) to use a system that allows high levels of daylighting at much lower insulating values.

5.2.5 Proposition #5 – Competency-Centered Team

Department of Environmental Protection Cambria Office Building competencies represented:

- Functional/technical skills
- Business acumen
- Creativity
- Quality decision making
- Interpersonal savvy
- Listening
- Motivating others
- Team integration
- Innovation management

Team Integration Example

The DEP Cambria Building project sought to integrate team members during the entire design process to improve the integrated design process. The following examples represent effective team integration events.

A ground source heat pump was selected for the heating system. The use of an experienced ground-source heat pump system designer combined with integrated design solutions contributed to keeping the cost of the system within an affordable range.

Collaboration between the mechanical designer, heat pump expert, and architect produced optimized building systems, resulting in significant load reductions. Key ingredients included building orientation, augmented thermal envelope, and thermal energy recovery. The result was cooling load reductions of 50% and total project cost reductions of $60,000.

An additional integrated design solution was discovered during a design meeting on the mechanical systems with the architect, mechanical engineer, mechanical contractor, energy modeler, developer, and lessee in attendance. The meeting began with a discussion about how to coordinate the installation of the piping, ductwork, etc., from the penthouse into the main building. The architect realized the inefficiencies and asked the mechanical designer where the mechanical space could optimally be located to reduce installation costs and simplify design. The optimum solution was determined to be a division of the central mechanical space into two rooms, each located on the first floor, one in each wing of the building.

The developer had little or no green building experience prior to the project, but he was willing to listen and work with the team on the sustainable issues important to the team, because he knew that they were part of the goals the team was working towards. His willingness to integrate into the team far outweighed his lack of knowledge, however, as multiple team members revealed during case study interviews.

The project went very well through the design phase, and it was the involvement of the owner that kept it on track and focused. The owner challenged the design team from an intent standpoint, not necessarily from a technical standpoint. Particularly the sizing issues stand out. Typically when a designer does a building like this, from an air-conditioning standpoint they want to make sure they have more than enough capacity. Thus, they throw every safety factor that they can into every calculation and end up with between 350 and 400 sf/ton. This is quite standard in classic design schemes, but the desire to minimize energy use and loads led to an understanding of how the building was being used. The owner emphasized that this was a building for field engineers who were going to be in the field 4 out of 5 days of the week. Because of this, liberties in occupancy loads could be taken that normally are not.

The architect, as the leader of the project, was highly motivated to move the project forward in an integrated fashion. For example, the mechanical engineer had not worked with any other architect who took the time and effort to get involved in the mechanical issues. There was a struggle with where to put the mechanical equipment, as traditionally an architect designs the building and the mechanical engineer is asked to fit the equipment into the room. It was determined that this approach was not going to work (and still achieve desired energy savings at conventional costs). The architect when asked where we wanted the mechanical room was shown some prime real-estate in the building (first floor core). This is ultimately where the room was located in the final design.

The Pennsylvania State University School of Architecture and Landscape Architecure Classroom and Office Buildingcompetencies represented:

- Functional/technical skills
- Informing
- Political savvy
- Written communications
- Team integration

Functional/Technical Skill Example

A heightened need for specific technical skill requirements during the design process has been identified for achieving high performance buildings. Four of these skills possessed by individuals on the design team for the SALA Building are illustrated in this section.

The project manager/project architect possessed a great deal of experience in the design process, not only early in the design but also throughout construction. This knowledge facilitated decisions early in the design that could be implemented in the field during construction. An example of the utilization of this competency is the relatively small number of conflicts encountered in the construction phase mechanical, electrical and plumbing coordination. No major conflicts were encountered and no ceilings needed to be modified to accommodate the MEP distribution systems.

Because the building systems were designed in an integrated fashion, importance was placed on knowledge of available materials and their associated characteristics. If a specific material is included in the design and available from only one manufacturer, the project can become a hostage to the supplier from both a cost standpoint and a schedule vantage point. The presence of this competency allowed for an achievable design scheme to be developed. The mechanical engineer on the SALA Building possessed this knowledge and was able to set effective performance parameters that were attainable by multiple materials. Custom fins were designed to act as shading devices because multiple commercial products that could meet the building's desired function were not available.

> "What you don't want to do is say at an early stage you are going to achieve a shading coefficient of one (product) and have only one provider that goes out of business when it is to be purchased."
>
> -Mechanical Engineer

The concept architect and mechanical engineer were both with internationally known firms in the field of sustainable design. Each had designed multiple buildings that required the optimization of envelope and building systems. The mechanical engineer was responsible for developing multiple options for the building concept at the design charette. Specific issues addressed included shape, orientation, and overall mass. Their input combined with the input of the landscape architect led to the final building design concept.

Specific knowledge and experience in the design of sustainable buildings was important on the SALA Building. If the design had been completed from the beginning to end with one mechanical firm, the benefit of the concept mechanical engineer's experience in the daylighting models might not have been realized. This is something that could have been done in-house by the local design development mechanical engineer, but at the time they did not have a great deal of experience in the energy models.

American Indian Housing Initiative Early Childhood Learning Center competencies represented:

- Functional technical skills
- Interpersonal savvy
- Process management
- Team integration

Process Management Example

The AIHI Project team, when compared to the other two case studies, spent as much time and effort consciously implementing process management measures as on the other projects. However, missing process management competencies resulted in shortcomings on this project not experienced on the others.

Missing team competencies included poor interdisciplinary information processing skills, effective process planning and process management skills, and clear goal setting. These missing competencies directly contributed to misinterpretation of responsibilities (architects performing rework on window/SIPS panel design), unproductive meetings, and mixed messages from the core design team to student volunteers throughout the design process.

The state of the design team was best summarized by a team member: “The technical knowledge required to perform the necessary planning were negligible or non-existent on the team.”

It was not clear to all design team members who had the responsibility of keeping the project on schedule. This was coupled with the fact that no timeline/schedule was developed and shared with all participants at the beginning of the project, which resulted in mis-timed decisions on multiple occasions. A specific example is the sequencing of ductwork and truss design. In an effort to *get work done*, the ductwork design was completed prior to the truss design completion. This resulted in workers occupying the same space and the need for redesign to correct the conflicts. Had each of these activities been coordinated and planned appropriately, the time spent redesigning could have been avoided.

5.2.6 Proposition #6 – Decision-Based Evaluation Model

All three case study projects employed a definable design process. The Cambria Office Building and the SALA Builidng utilized contracts and design phase definitions developed by the American Institute of Architects (AIA) to guide the process. Neither actively employed a decision-based methodology, to manage or assess the sequencing of activities; therefore, neither project provided positive or negative support for the proposition.

American Indian Housing Initiative Early Childhood Learning Center event categories represented:

The AIHI project did employ a decision-based management methodology during certain stages of the project; however, it was not actively implemented throughout the project. Early in the project, a plan was developed. The University of Washington team would create the conceptual and schematic design, Penn State University team would complete the design development and detailed design, and graduate students at Penn State would create construction documents. However, as the design process unfolded, this plan was not adhered to; so, key milestone deadlines were not met. A large source of waste resulted, as students in various classes intended to help complete design development and detailed design through course projects.

Throughout the design process, decisions were not being made in conjunction with the milestones that had been developed. At a critical point of the process, a design process facilitator was hired to map the remaining design process through the planned start of construction. The approach focused on the decisions that needed to be made in the time remaining prior to the beginning of construction. The resulting product was a clearly defined process, including intermediate deadlines for key decisions that ultimately aided in the management of the process, and key information requirements needed for decisions. Team members were given the deadlines for key decisions that needed to be made, and information began to flow more effectively than prior to the meeting. The result was that even though waste had been prevalent in the design process leading up to the introduction of the design process facilitator, initial construction activities began on time, even though they were in great jeopardy prior to the meeting.

5.3 Summary

The intent in this chapter was to introduce the case study projects investigated in the research and to present illustrative examples of the findings of internal validity tests for each research proposition. To achieve this goal, the chapter presented the analyses of the design processes for three contemporary building projects in the United States. Every phase of the event identification process has been described and the results of supporting events presented. Through triangulation of resources and a regimented research process, it has been reliably determined that all propositions exhibit internal validity at minimium from one case study to another. Proposition validation through a cross-case analysis has been conducted and is presented in Chapter 6.

Chapter 6

Case Study Proposition Validation – Cross Case Synthesis

6.1 Research Results: Cross-Case Analysis Findings

This chapter presents the findings of the cross-case synthesis analysis for proposition testing. A discussion ensues presenting the key components of the integrated design process including influential guiding decisions and key competencies as determined through case study proposition testing. Each proposition has also been analyzed for event support and a determination of validation made. Those results are presented in this chapter.

6.2 Cross-Case Synthesis - Proposition Validation

Proposition validation has been defined for the research as appropriate replication of individual proposition events indicating a matching of patterns either between or within cases. Replication has been defined in Section 3.3.5 as multiple internally validated events (within individual cases or across cases) that support the proposition positively or negatively.

The number of replications sought for validation have been determined in Section 3.3.6 and presented in Table 3-7. The final results of proposition event replication are presented in Table 6-1

Table 6-1: Proposition Event Replication Findings

	Replications Required for Validation	**Total Number of Replications**	**Event Occurrences by Project**		
			Cambria	**SALA**	**AIHI**
Proposition #1 *Function Based Process Design*	3	7	10	4	4
Proposition #2 *Design Decision Characteristics*	4	4	3	1	1
Proposition #3 *Decision Timing & Sequencing*	5	9	15	17	13
Proposition #4 *Pull Driven Commitments*	5	6	11	8	11
Proposition #5 *Competency Centered Team*	6	8	22	15	16
Proposition #6 *Decision Based Evaluation Model*	4	0	0	0	2

6.2.1 Proposition #1 – Function Based Process Design: Validation Results

A total of eighteen events were identified as events supporting Proposition #1 (events can be found in Appendix E). As determined in Section 3.3.6, three internally validated cross-case replications are required to validate Proposition #1. The proposition has been validated by seven internally validated event replications. Each event has been analyzed and the following categories developed to provide a summary of the desired attributes encountered on the three high performance building case study projects. The five different categories of desired building/project attributes identified from the three case study projects are:

1) Reduce energy consumption
2) Develop a sustainable design
3) Improve indoor air quality
4) Promote sustainable and high performance design
5) Meet the owner’s desires

Internally validated events (event id):

Cambria

- Advance concept of green building (CAM-JT-01-02 & CAM-NREL-01-01)
- Reduce energy use (CAM-JB-01-01, CAM-JT-01-01, CAM-JM-01-01 & CAM-MS-01-01)
- Set sustainable design example (CAM-JT-01-02 & CAM-NREL-01-02)

AIHI

- Reduce energy use (AIHI-DR-01-01 & AIHI-AF-01-01)
- Design for constructability (AIHI-DR-01-02 & AIHI-SW-01-01)

SALA

- Utilize sustainable systems (SALA-RR-01-01 & SALA-AT-01-01)
- Educate individuals on sustainability (SALA-RR-01-02 & SALA-JN-01-03)

6.2.2 Proposition #2 – Design Decision Characteristics: Validation Results

A total of five events were identified as supporting Proposition #2. As determined in Section 3.3.2, four internally validated cross-case replications are required to validate Proposition #2. The requirement for internal validation of Proposition #2 was determined to be two different individual representations of an embedded design process that met the requirements of the proposition. For example, the project manager on the

AIHI project described in detail the design process in terms that were easily translated in the decision based design framework presented in the proposition. When describing the design process, the architect on the same project referred to multiple facets of the model that was developed from the project manager's interview but did not describe every step of the process exactly the same. The duplication of decisions and information gathered both from the project manager and architect serve as triangulation of information and result in internal validity. The proposition has been validated by four internally validated cross-case replications; including the development of six decision based design process models utilizing the Modified Decision Based Design Methodology (DDNM). Each event model can be found in Appendix I. Proposition #2 has been shown to be an accurate way to represent the design process for high performance buildings through validation.

6.2.3 Proposition #3 – Decision Timing & Sequencing: Validation Results

A total of forty-five events were identified as events supporting Proposition #3 (all events can be found in Appendix F). As determined in Section 3.3.2, five internally validated cross-case replications are required to validate Proposition #3. The proposition has been validated by nine internally validated event replications. Each event has been analyzed, and the following categories were developed to provide a summary of the desired key decisions and the appropriate timing of the decisions as encountered on the three high performance building case study projects. The eight different categories of decisions identified from the three case study projects are:

Definition Phase

1) Building configuration/orientation determination
2) Building energy load determination/minimization
3) Building systems parameter testing
4) Defining building functional use

Design Phase

5) Building systems equipment selection
6) Building systems distribution selection
7) Materials selection

Documentation Phase

8) Design documentation

Internally validated events (event id):

Cambria

- Modifications to original ‘box’ design (CAM-JB-03-05 & CAM-NREL-03-01)
- Elimination of penthouse mechanical room (CAM-NREL-03-07, CAM-JM-03-01, CAM-JT-03-01 & CAM-JB-03-04)
- Elongated building configuration (CAM-JB-03-01 & CAM-NREL-03-10)
- Building systems considerations (CAM-NREL-03-03, CAM-NREL-03-02, CAM-NREL-03-04, CAM-NREL-03-06 & CAM-JB-03-03)

AIHI

- Conceptual design review (AIHI-DR-03-02 & AIHI-SW-03-07-)
- Incomplete design documentation (AIHI-DR-03-03 & AIHI-SW-03-04)
- Control system selection (AIHI-DR-03-05 & AIHI-R?-03-01)

SALA

- Transition of MEP design responsibilities (SALA-JN-03-01 & SALA-JS-03-02)
- Heat recovery system design (SALA-JS-03-02 & SALA-JN-03-05)

6.2.4 Proposition #4 – Pull Driven Commitments: Validation Results

A total of thirty events were identified as events supporting Proposition #4 (all events can be found in Appendix H). As determined in Section 3.3.2 five internally validated cross-case replications are required to validate Proposition #4. The proposition has been validated by six internally validated event replications. Each event has been analyzed and the following categories developed to provide a summary of the desired information pulled by key decisions as encountered on the three high performance building case study projects. The different categories of decisions and information required to reach sound commitments identified from the three case study projects are:

Building configuration/orientation determination

1) True solar north
2) Functional program (including occupancy times, numbers, use, etc.)
3) Preliminary energy models (assumptions for u & r values for walls, roof, windows)

Building energy load determination/minimization

1) Detailed energy model
2) Detailed daylighting model
3) Functional program including occupancy times, numbers, use, etc.)

Building systems equipment selection

1) Desired equipment location
2) Architectural layout and adjacent systems
3) Anticipated building loads and associated parameter tests

Integrated system combination design strategy selection

1) System combination cost estimates
2) System combination expected energy performance

3) Cross combination system component consideration/evaluation

High Performance material selection

1) Available high performance materials
2) Number of suppliers offering the material
3) Supplier location in proximity to the building project

Internally validated events (event id):

Cambria

- Computer models to inform daylighting decisions (CAM-MS-05-01 & CAM-JB-05-04)
- Energy system sizing: building occupancy use (CAM-JT-05-02 & CAM-JB-05-01)
- Heating system selection: peak & avg. building loads (CAM-JB-05-02 & CAM-JM-05-01)

AIHI

- Control logic: mechanical systems design (AIHI-DR-05-01 & AIHI-R?-05-01)

SALA

- Shading/glazing design: daylight model (SALA-RR-05-01 & SALA-AT-05-01)
- Heat recovery: energy model (SALA-JN-03-05 & SALA-JS-03-02)

6.2.5 Proposition #5 – Competency Centered Team: Validation Results

A total of fifty-three events were identified as events supporting Proposition #5 (all events can be found in Appendix I). As determined in Section 3.3.2, six internally validated cross-case replications are required to validate Proposition #5. The proposition has been validated by eight internally validated event replications. Each event has been analyzed and the following categories developed to provide a summary of the desired competencies as encountered on the three high performance building case study projects. The different categories of competencies identified from the three case study projects are:

1) Functional/technical skills
2) Informing others
3) Dealing with ambiguity
4) Business acumen
5) Creativity
6) Quality decision making
7) Interpersonal savvy
8) Listening
9) Motivating others
10) Problem solving
11) Process management
12) Written communications
13) Team integration
14) Innovation management
15) Timely Decision Making
16) Personal learning
17) Priority setting
18) Self knowledge
19) Building effective teams
20) Understanding others

Internally validated events (event id):

Cambria

- Technical knowledge: ground source heat pump (CAM-NREL-06-03 & CAM-JM-06-07)
- Team integration (CAM-JM-06-09 & CAM-JT-06-01)
- Risk assessment: heat pump/raised floor (CAM-JT-06-05 & CAM-JB-06-03)

AIHI

- Informing others: ICF/SIP design (AIHI-DR-06-03, AIHI-SW-06-05 & AIHI-AF-06-01)
- Process management (AIHI-DR-06-04 & AIHI-AF-06-03)

SALA

- Sustainable design experience (SALA-JN-06-01 & SALA-RR-06-06)
- Energy modeling (SALA-RR-06-05 & SALA-JS-06-02)
- Information transfer (SALA-JS-06-04 & SALA-AT-06-01)

6.2.6 Proposition #6 – Decision Based Evaluation Model: Validation Results

A total of two events were identified as supporting Proposition #6 (the events can be found in Appendix G). As determined in Section 3.3.2, four internally validated cross-case replications are required to validate Proposition #6. The proposition has not been validated by four internally validated event replications.

The main factor contributing to the failure of validation for Proposition #6 is the relatively new approach it presents to managing and assessing the design process. While decision-based design has been determined to be an accurate way to represent the design process for buildings (Proposition #2), only one of the three case studies investigated approached the project in this manner. Instead an activity-based approach, as facilitated by the traditional over-the-wall design approach, was implemented leading to more traditional milestone/activity based management methods. The missing decision-based design process methodology in the three case study projects led the research team to develop the Design Process Evaluation Model for High Performance Buildings (DPEM^{HP}) (Section 4.2). Propositions #1-5 are tied together by Proposition #6 and validation of the DPEM^{HP} through validation of Propositions #1-5 can be viewed as the first step in validating Proposition #6.

6.3 Summary

A cross-case analysis of the six case study propositions has led to the validation of Propositions #1, 2, 3, 4 and 5. In addition to the validation of the propositions, a list of key decisions that add value to the design process of high performance buildings have been identified, as well as the competencies that are desired of the individuals making these decisions. No decision-based design model or evaluation process existed on any of the three case study projects negating Proposition #6. This absence led the researcher to develop a Decision Based Design Process Evaluation Model for High Performance Buildings that is supported by the validated propositions. In Chapter 7 the data collected in case study interviews by the researcher during Proposition #2 testing for energy systems are presented in greater detail. The final design model developed as part of this research to provide guidance in the energy systems design on high performance buildings is presented and compared to another proven design process model for traditional buildings.

Chapter 7

Design Process Evaluation Model

7.1 Overview

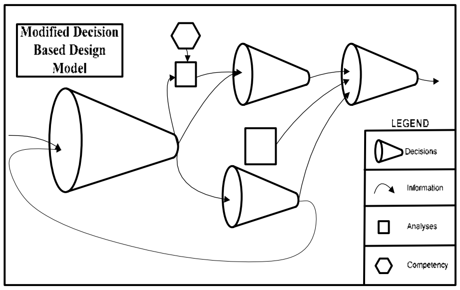
This chapter presents the three main parts of research that led to the final Design Process Model for High Performance Buildings (DPM^{HP}) developed for utilization in the evaluation of the engineering design process for high performance buildings (see Figure 7-1).

Chapter 2 provided a summary of current decision based engineering design models and the basis for their development and use. Section 7.2 of this chapter provides information regarding the development of a representative decision based model for the design process of high performance buildings. The Design Decision Network Model (DDNM) format that was presented in Section 1.2.3 was used to develop this model utilizing data collected through case study projects.

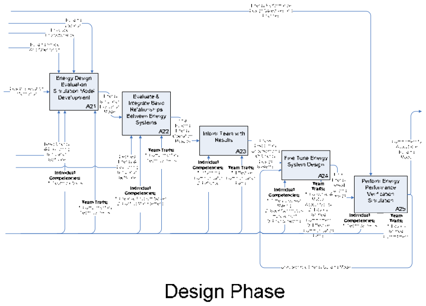
This information was then taken and presented in Section 7.4 in a more traditional IDEF^0 modeling technique. The IDEF^0 modeling technique has been selected and utilized to develop an industry level decision and competency-based evaluation model for high performance buildings.

Once developed, the model was compared to an established design process methodology, developed with the same modeling methodology as part of the Integrated Building Process Model (IBPM) research conducted by Sanvido, et al. (1990). Section 7.4 presents key similarities as well as differences that have been identified for the general design process model (IBPM) and the more specialized DPM^{HP}. New knowledge is presented for the design process of high performance buildings based on the process model comparison and case study data analysis in this chapter.

Section 7.2 – Design Decision Network Model (DDNM)



Section 7.3 – High Performance Design Process Model (DPM^{HP})



Section 7.4 – DPM^{HP} and Integrated Building Process Model (IBPM) Comparison

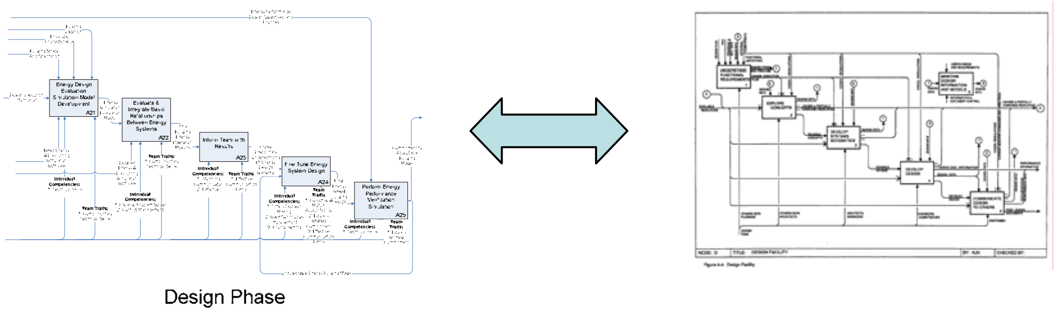


Figure 7-1: Main Research Components of Development of the Design Process Model for High Performance Buildings (DPM^{HP})

7.2 High Performance Design Decision Network Model (DDNM^{HP}) Development

Proposition #6 of the case study research states, *identification and development of a decision-based methodology to map the design process in a measurable manner results in an improved design process.* None of the three case study projects investigated consciously set out to define a decision based design process at the beginning of the project. Therefore, no decision-based design model of any of the projects could be utilized in this research. The AIHI project employed a design process consultant when the project's design process had fallen behind schedule prior to the start of construction. The SALA and Cambria projects both relied heavily upon the AIA design phase structure to guide the design process. While none of the projects intentionally embarked on a decision based design process, all three exhibited every component of this process as defined in Section 1.2.3. Models have been developed for all three projects to capture the design process for the project's energy systems design (Appendix I). These process models were then analyzed for the value added to the process based on decision sequencing and timing. Each proposition event that was a contributing basis for the process model was evaluated for value or waste introduced to the overall process based on the categories of value and waste presented in Section 3.3.3. Results of the value/waste analysis can be found for Propositions #1, #3, #4 and #5 in Appendix J. Once the decision process was developed, desired competency involvement was considered and assigned to the decisions and analyses that make up the process.

Each proposition developed for the case study research played a contributing factor in the development of the DDNM^{HP}. The relationship between all propositions and the model are presented.

Relationship between Research Propositions and the Model

Proposition #1 –Function Based Process Design: The DDNM^{HP} is a process model for energy system design. It places a heightened emphasis on the design of the building mechanical, electrical, lighting, and envelope systems. Identification of the aspiration to optimize energy performance has allowed the process model to be engineered based on these desires.

Proposition #2 – Design Decision Characteristics: This research has demonstrated that the design process is made up of a network of decisions, commitments, and analyses all performed by individuals possessing specific competencies. The DDNM technique has been utilized to develop a high performance design process model to incorporate these attributes.

Proposition #3 – Decision Timing & Sequencing: Each individual decision within the network decisions that have been identified in this research to constitute the DDNM^{HP} has been evaluated specifically for its timing in the design process. The value impact on the overall design process with respect to its timing has been identified. The model strives to represent appropriately decisions so that Level II decisions can be made effectively informing subsequent decisions, commitments and analyses.

Proposition #4 – Pull Driven Commitments: During development of the DDNM^{HP} the information required to inform decisions was determined when selecting the time and sequence of the decisions and information required to make them. Decisions were analyzed for the information that is required to reach an informed commitment. Information needed for a decision was sequenced prior to the decision and any analyses or commitment required to produce the information included in the model.

Proposition #5 – Competency Centered Team: As the model was developed, every decision and analyses was evaluated independently for key competency requirements. Key competencies for the high performance energy system were initially identified through analysis of case study results. After the DDNM^{HP} was developed a systems-based analysis (Langdon and Marrelli, 2002) was performed, and additional competencies were identified and added to the model. After competencies were assigned, the intial decision-based design model for high performance buildings (DDNM^{HP}) was complete.

After the initial model was developed, each decision was then evaluated independently for the value that it added to the overall process based on its timing and sequence relative to the information, commitments and decisions that make up the process. Cyclical decision networks (see Figure 2-7) were closely evaluated for waste due to rework during this step of the model development. In the final model, all cyclical decision networks were eliminated and the potential waste that would be introduced to the design process removed. Figures 7-3, 7-4, and 7-5 present the final DDNM^{HP}.

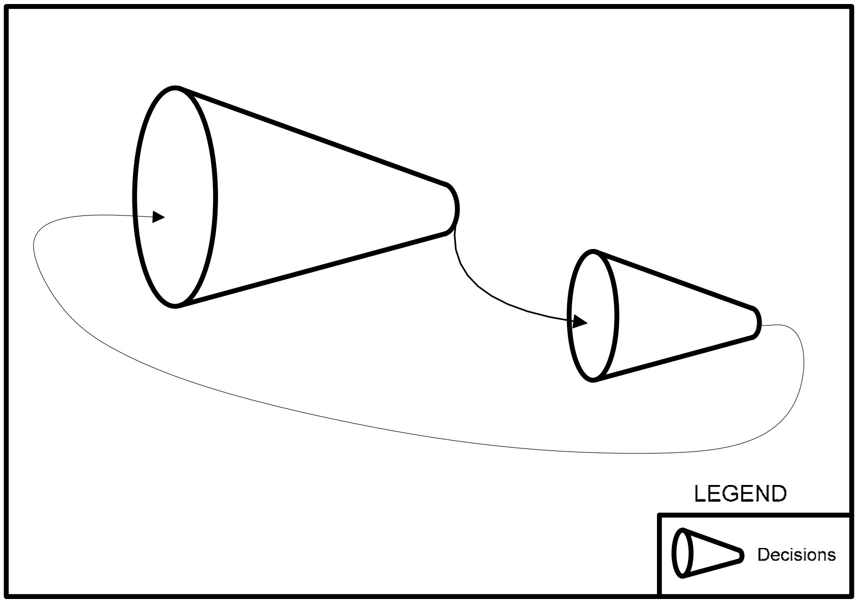


Figure 7-2: Cyclical Decision Network Loop

7.2.1 Design Decision Network Model for High Performance Buildings (DDNM^{HP}) – *Definition Phase*

Traditionally labeled pre-planning, conceptual and schematic design phases, by the American Institute of Architects (Haviland, 1994), the *define phase* of the DDNM^{HP} is the first phase of the design process. This terminology effectively articulates the goal of the phase and assists in focusing efforts in the proper direction. The *define phase* for energy optimization is closely aligned with the traditional design process, with team formation, project goal and objectives determination and information gathering completed at this time. The *define phase* of the high performance decision based design process includes creation of a building purpose and program definition. Deliverables include site evaluation and diagrams indicating the building on the site, energy system project objectives, building system performance assumptions, as well as energy and lighting load determinations. Analysis tools that are utilized to inform decisions in this phase are milestone schedules, preliminary energy models, regional climate analyses, a design charette and interdisciplinary integrated design opportunity identification. The complete process model for the *definition phase* of the DDNM^{HP} is found in Figure 7-3.

7.2.2 Design Decision Network Model for High Performance Buildings (DDNM^{HP}) – *Design Phase*

The American Institute of Architects has developed the schematic and design development phases to bridge the definition activities and construction documentation activities in the design process while focusing efforts on developing the design through coordination of systems. These phases are often the most ambiguous and costly for the project design team. Most costs are incurred because of rework caused by lack of team commitments relating to the design. In the energy optimization process model, these two traditional phases are replaced with the *design phase*. In the *design phase* of the decision based design process, a heightened emphasis is placed not only on coordinating system details, but on integrating them to optimize their performance. Key decisions include alternative energy systems identification, cost and energy performance analysis, and ultimately the coordination of systems details. Key competency requirements include mechanical and electrical systems knowledge, mechanical and electrical equipment knowledge, and creativity and team integration. The complete process model for the *design phase* of the DDNM^{HP} is found in Figure 7-4.

7.2.3 Design Decision Network Model for High Performance Buildings (DDNM^{HP}) – *Documentation Phase*

Traditionally titled the construction document and shop drawing phase of the design process, the *documentation phase* in the energy optimization process model aims to remove both the traditionally perceived and actual barrier of incomplete design documents through an integrated design and detailing activity. Upon completion of the design facility phase, documentation ensues. Construction documents and detailed material and equipment specifications are created with final details developed for fabrication and construction purposes. System details are developed and coordinated by those professionals possessing the appropriate construction skills and knowledge. Competency requirements include problem solving capabilities, interpersonal skills, computer drafting technical knowledge relative to the energy and electrical systems. The construction estimate and schedule are finalized and construction begins. A key decision for the document phase of high performance buildings is the accurate documentation and location of energy systems and their associated distribution systems. The complete process model for the *documentation phase* of the DDNM^{HP} is found in Figure 7-5.

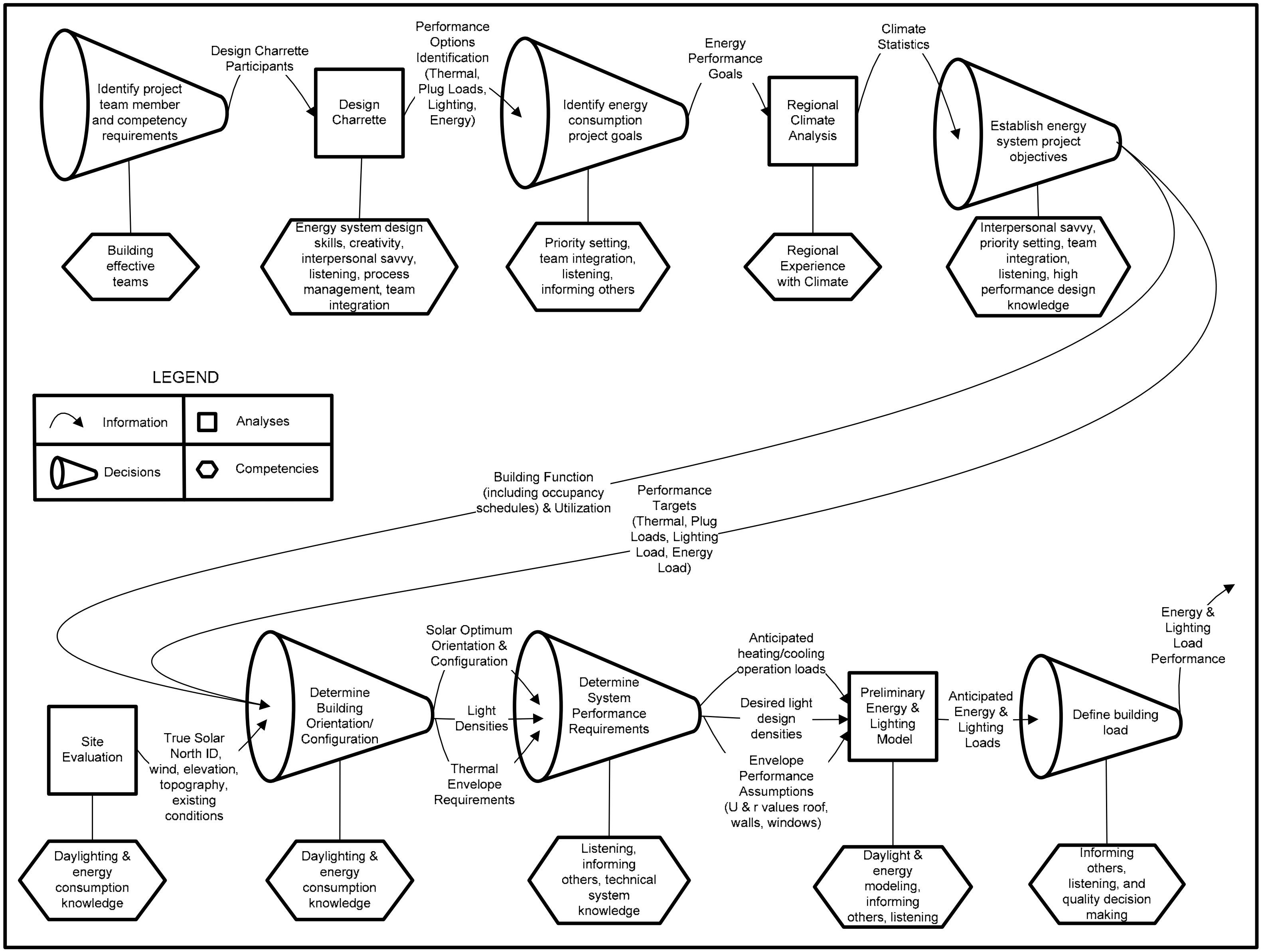


Figure 7-3: Design Decision Network Model (DDNM^{HP}) – Definition Phase for Energy Systems

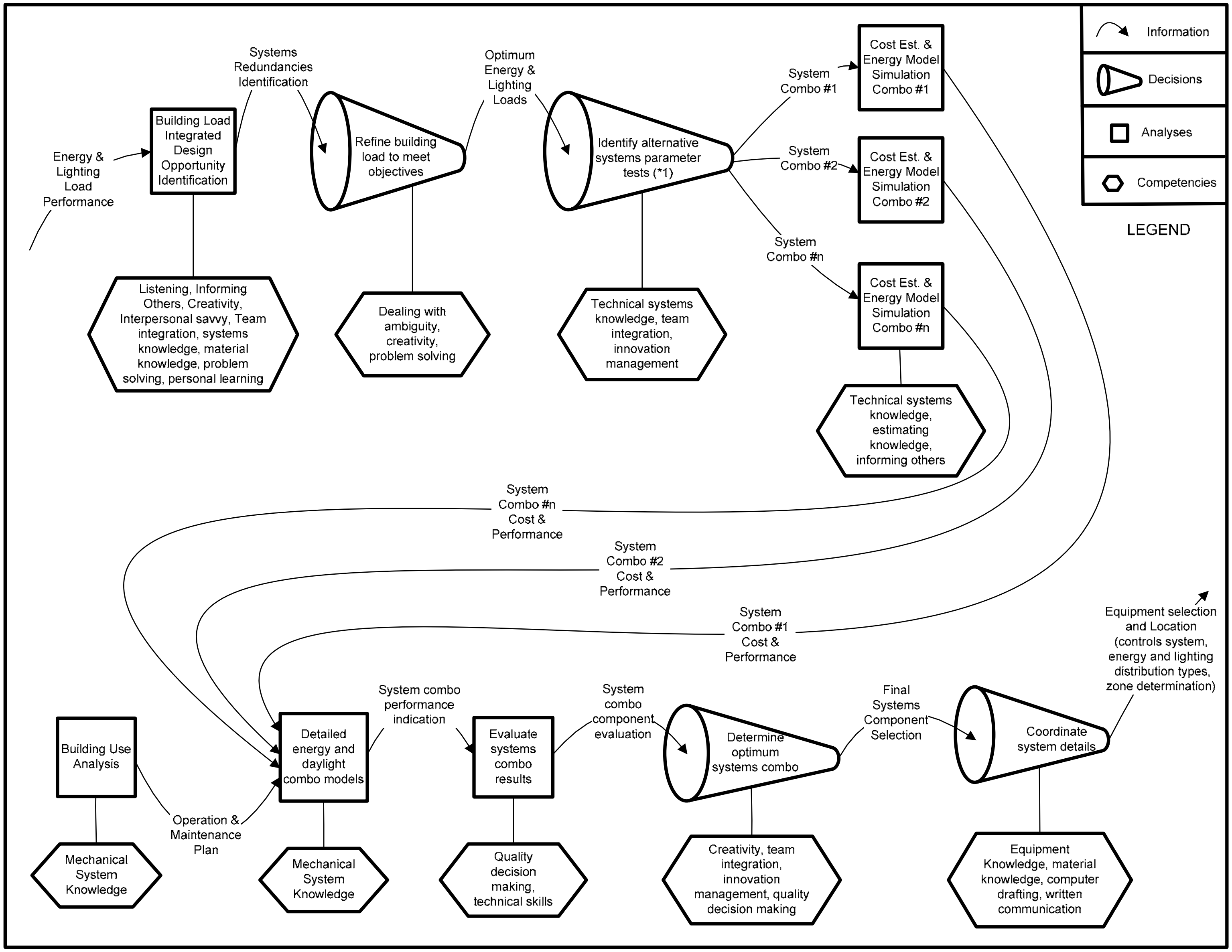


Figure 7-4: Design Decision Network Model (DDNM^{HP}) – Design Phase for Energy Systems

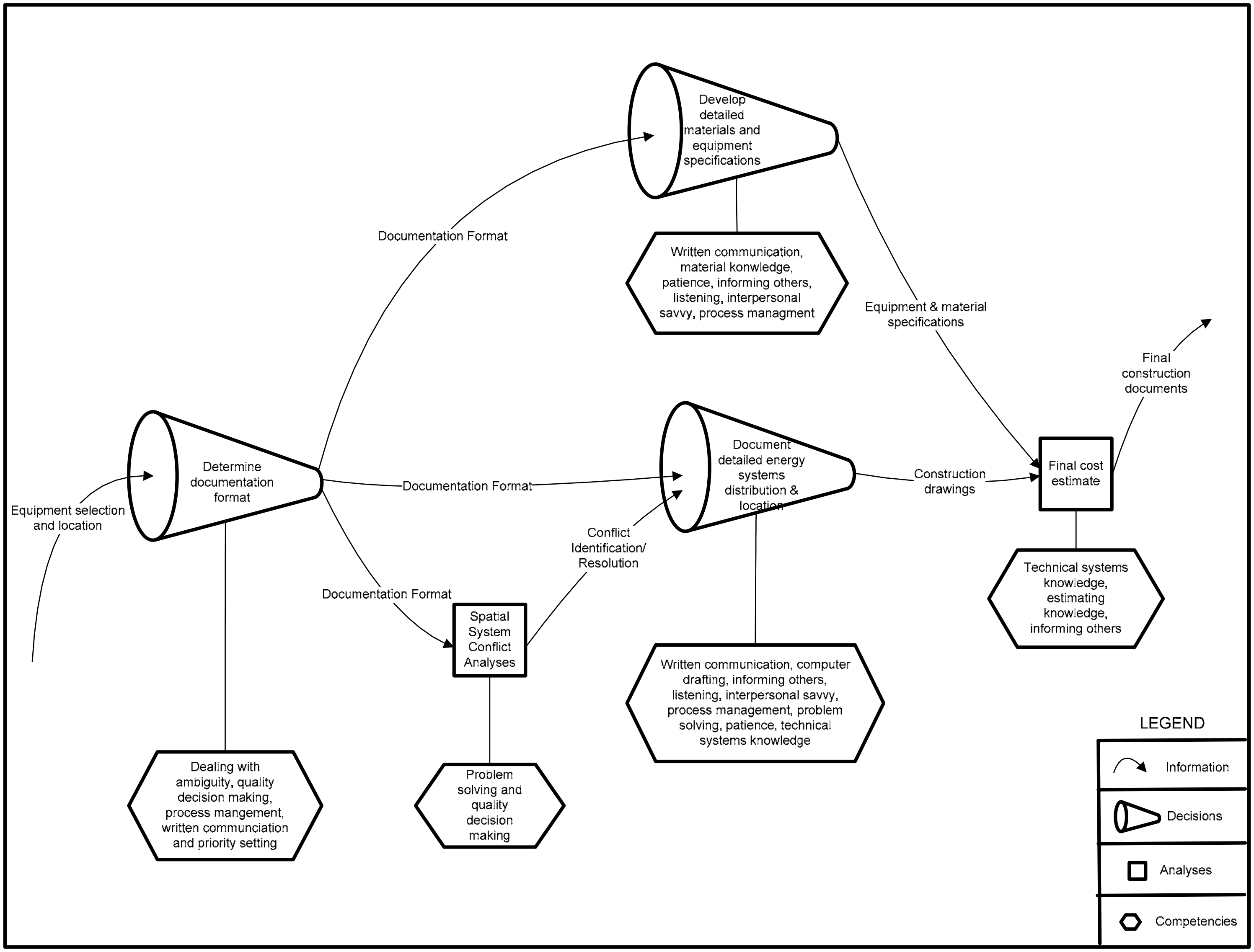


Figure 7-5: Design Decision Network Model (DDNM^{HP}) – Documentation Phase for Energy Systems

7.3 Design Process Model for High Performance Buildings (DPM^{HP})

Design decisions concerning the integration of energy saving building components in buildings need careful consideration during the building design process (DeWilde, 2004). The Design Process Model for High Performance Buildings (DPM^{HP}) is a product of this research that enhances continuous process evaluation throughout design and allows for a comparison of the model through an association evaluation with seminal design process modeling work in the research field. The development of the DPM^{HP} and an explanation of the decisions made pertaining to the selection of a modeling methodology utilized in its development are explained in detail in this section.

For this research, it has been determined that the final process modeling tool needs to be:

1. as simple as possible in an effort to increase use and understanding of the final process model for evaluation purposes,
2. have the ability to address team competency requirements in the design process,
3. adequately consider the decision making process of high performance buildings,
4. illustrate the basic dependencies between decisions and available information and the mechanisms needed to generate commitments, and
5. allow for a direct comparison to a proven design process model.

After a thorough review of modeling techniques, Integration Definition for Function Modeling (IDEF^0) was selected because it best met these requirements. The IDEF^0 model represents a process as a series of diagrams. It describes mainly the informational relationships between activities. In these diagrams the activities that make up the process are depicted as boxes. Interfaces between the activities are depicted as lines with arrows that either enter or exit an activity box. Inputs enter activities from the left, controls from the top, mechanisms from the bottom and outputs leave activities from the right. IDEF^0 uses a hierarchy of diagrams. One top-level diagram (A0) shows the process as one activity only; this activity is broken down into more detailed diagrams (A1, A2, A3, …) that can themselves be decomposed until the tasks are described at a level necessary to support the goal of the process model.

Four kinds of interfaces are distinguished (Figure 7-6):

Inputs: Information or objects required to perform activities
Outputs: Information or objects that are created when an activity is performed
Controls: Conditions or circumstances that govern the activities performed, and
Mechanisms: Persons or devices that carry out the activity

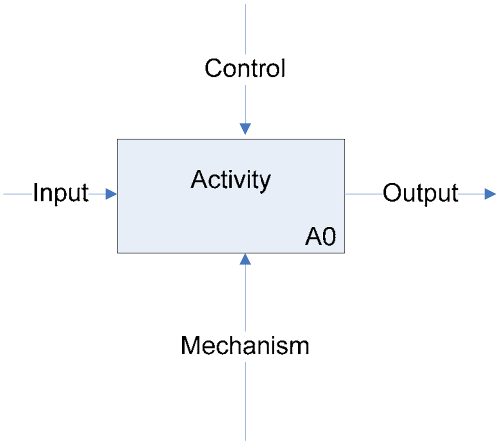


Figure 7-6: Schematic representation of the IDEF^0 Model format

Compared to the DDNM, the IDEF^0 model has direct relationships. The information considered in the decision making process acts as inputs into activities that are performed. These activities in turn produce outputs equivalent to the commitments that are reached in the decision model. The decisions are made by individuals possessing specific competencies and these competencies are vital mechanisms to be considered in the design process. Finally, the ambiguity in the DDNM^{HP} is controlled by many factors. These controls, often classified as the elements that influence or determine the process of converting input to output, in the IDEF^{0} model are represented as arrows entering the top of the activity. In the DPM^{HP} four kinds of interfaces are distinguished based on the proven IDEF^{0} modeling methodology already developed**:**

Information: knowledge acquired through analysis or experience
Commitments: obligation or responsibility for a future action sufficient in its level of detail to act as information for future decisions or analyses
Controls: the elements that influence or determine the process of converting information to commitments
Competencies: underlying characteristic of an actor which results in effective and/or superior performance in decision making

7.3.1 Competencies Identification

Chapter 2 discussed the five primary competency identification and modeling approaches applied by researchers and organizations in the United States today. A modified process-driven approach has been utilized to analyze the existing competencies identified through the process model building techniques presented in Section 7.3.2 and identify and assign potential competency requirements for teams engaged in the energy system design of high performance buildings.

Process-Driven Competency Identification for Energy System Design

The process-driven approach to competency modeling attaches much weight to the work process that is performed. This emphasis makes the approach most suitable for project-based competency identification and modeling. The integrated design process is at the heart of high performance building design and an added emphasis is placed on effective interdisciplinary collaboration. These two facts make the process-driven approach a natural competency identification method for teams participating in the design of high performance buildings. In the process-driven approach, a model of the process is needed initially. The job model should include inputs, process, outputs, consequences, feedback and conditions. After each of these items is defined, competencies are systematically built by specifically focusing on each item of the job model. The majority of project competencies emanate from the process steps. Competencies have been identified within this framework for the Level II high performance design process decisions and analyses.

Each level two decision and analyses has been evaluated independently and the skill and knowledge requirements necessary to perform each activity identified. These skills and knowledge requirements were then grouped into competency requirements that encompass the entire process. The competencies associated with the DPM^{HP} have been developed with this method, and the results along with corresponding case study examples are found in Table 7-1.

Table 7-1: Competency Identification for Integrated System Design Activity

High Performance Design Skill and Knowledge Requirement	**Project Team Competencies by Name (Lombardo and Eichinger, 2003)**	**Corresponding Case Study Event**
Skill Requirements	***Competencies***	
Judgment	Quality Decision Making	SALA-AT-06-02
Critical Thinking	Timely Decision Making	AIHI-AF-06-03
Idea Evaluation	Informing Others	SALA-JS-06-04
Idea Generation	Problem Solving	CAM-NREL-06-04
Systems Perception	Interpersonal Savvy	CAM-JM-06-10
Systems Evaluation	Learning on the Fly	
	Personal Learning	CAM-JM-06-04
	Priority Setting	SALA-AT-06-01
Speaking	Interpersonal Savvy	CAM-JB-06-02
Active Listening	Patience	
Coordination		
Technical Design	Functional/Technical Skill	AIHI-SW-06-01
	Technical Learning	
Architectural Design	Creativity	AIHI-SW-06-04
Knowledge Requirements	***Competencies***	
Mechanical, Architectural, Structural, Electrical Systems	Self Knowledge	CAM-JT-06-03
	Building Effective Teams	SALA-RR-06-02
Sustainable Systems Knowledge	Understanding Others	AIHI-RX-06-03

7.3.2 Design Process Model for High Performance Buildings (DPM^{HP})

AFITEP (1998:7) states that “there is no standardization of phases that is valid for all projects”. This view is supported by many, including Gidel, et al. (2005). This does not pose many problems provided that in a project the phases are clearly defined, that all participants share the same vision of the objective of each phases and that all participants have the same perception, at all moments, of the phase in which the project is currently in (AFITEP 1998:7). This research has also shown that the building design process is engineered based on the project’s desired functions. Therefore, projects that have similar desired functions should utilize a similar process.

In the traditinoal linear design process, design phases are defined by the American Institute of Architects as concept, schematic, design development, and construction documents. These phases were developed to define the design process for a traditional contractual delivery process (i.e. lump-sum contract). However, with the advent of fast-track projects and new contracting methods, these phases have become blurred and the objectives, responsibilities and perception of the present state of design at any given moment in time becomes increasingly blurred. As discussed in Section 2.1.1**,** the integrated design process is the underlying basis for design activities in the design of high performance buildings. A new approach to design that involves more design participants in the process at all stages of design. This increase in participant involvement only further complicates the complex AIA phase definitions. In an effort to minimize confusion in the design evaluation process, the DPM^{HP} model for the design process begins with three basic and self-explanatory phases. The definition phase, design phase, and documentation phase (see Figure 7-7). These phases represent Level I of the DPM^{HP} and have been described earlier in Section 7.2.

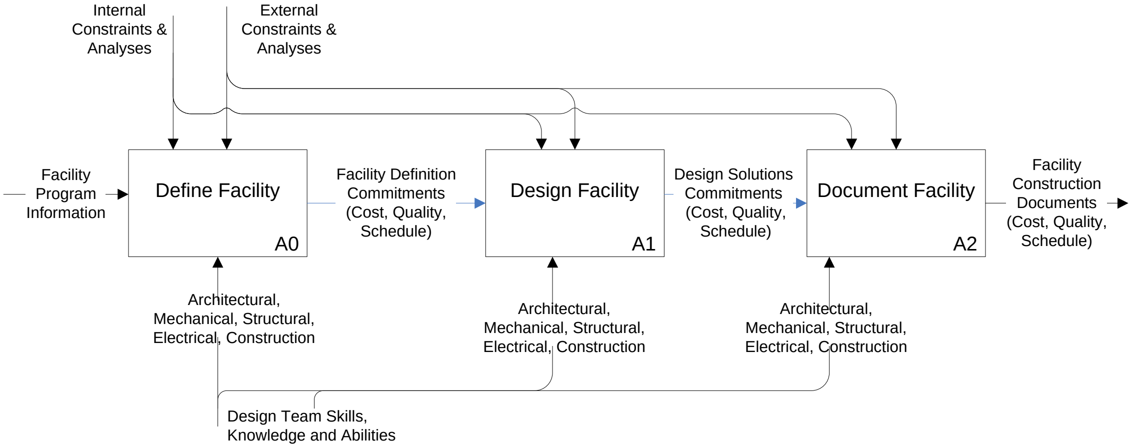


Figure 7-7: Level I High Performance Design Process Model (DPM^{HP})

7.3.3 Level II Definition Model

The Level II Definition Model strives to provide an accurate representation of the design process for a specific aspect of high performance buidlings. This model has been developed for the building envelope design and energy components of the factility based on a thorough literature review, a two day industry roundtable discussion, design professional interviews, participation in multiple professional conferences (Greenbuild 2003, 2004, GBA CIB 2003, CRC 2004), the DDNM^{HP}, and findings from the case study research. A focus has been placed on modeling the building energy systems in greater detail. Alternate systems could have been selected, and the procedure developed in this research utiliized to model the process and evaluate it on a value/waste basis implmented. However, to develop a project-level evaluation decision-based process model would have been too great in scope for this research and unnecessary for the creation of a Design Process Evaluation Model for High Performance Buildings (DPEM^{HP}). The heightened value high performance buildings place on the facility's energy consuming systems, has led the author to select the building envelope and mechanical system design (energy system) for Level II definition development. The model is intended to serve as part of the DPEM^{HP} decision based tool presented in Section 8.2 to aid in the assessment of sequencing, timing of key decisions and competency involvment in the design process.

During the case study data collection phase of the research, it became apparent that a decision based process modeling tool did not exist during the design of the projects. The absence of this tool, resulted in the inability of all three projects to implement a plan that allowed for tesing of Propostition #6. This research does not aim to validate the decision based process model that is presented in the following sections, but rather presents a tool that can be implemented on future projects and be used as a tool to analyze the design processes for high performance projects. Figure 7-8 shows the Level II Definition Model for the definition activity of energy system design.

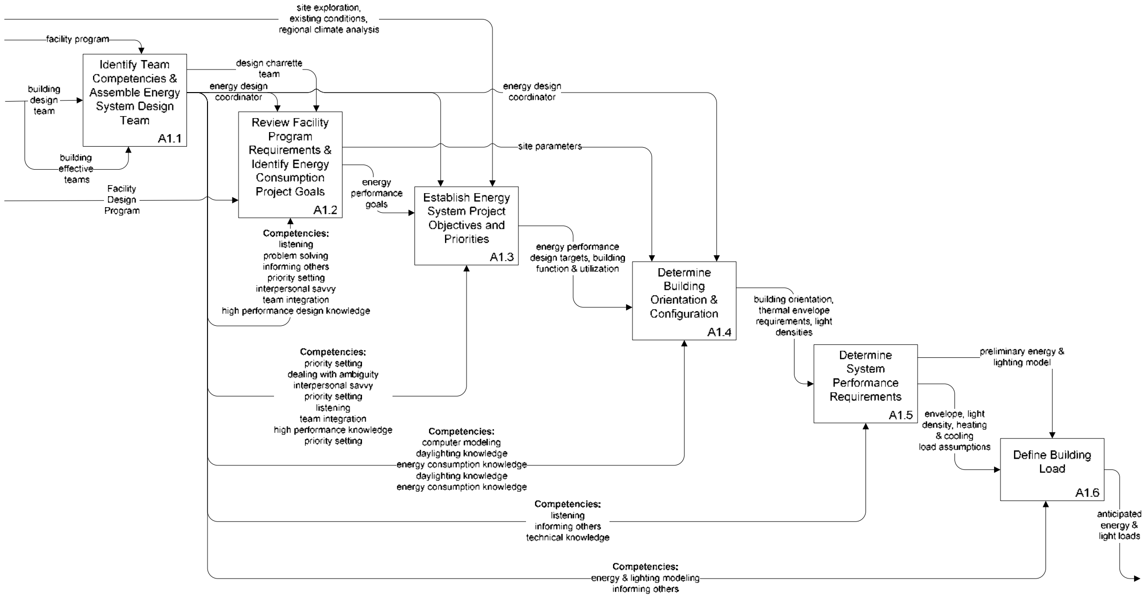


Figure 7-8: Level II DPM^{HP} - Definition Activity (A0)

Identify Team Competencies & Assemble Energy System Design Team (A1.1)

Assembling high performance teams is the first critical activity in the energy optimization design process. Critical team traits that require consideration when assembling the high performance team have been presented in Table 7-1. These competencies are represented by arrows entering the bottom of the decision boxes in the

DPM^{HP}. These traits aid in many facets of the design, enabling effective delivery of the key activities that make up the energy optimization process.

Review Facility Program Requirements & Identify Energy Consumption Project Goals (A1.2)

The overall function performed at this point is the acquisition and processing of information relating to the energy systems of the desired facility. Typically the information gathered includes the wants and requirements of the owner. Broad project goals that pertain to the energy systems are identified by the team. A design team charette, a multi-disciplinary collaborative event, has gained wide spread use in the design of high performance buildings in aiding in the identification of project goals (Eisenberg and Reed, 2003; Mendler, 2001; Watson, 1996).

Establish Energy System Objectives and Priorities (A1.3)

Identification of facility design guidelines allows for the formulation and establishment of overall energy performance objectives and priorities for the project. These objectives and priorities are critical and will act as the measurement criteria when evaluating the overall energy design in the design phase of the process. Examples of objectives that should be considered during the definition phase are overall energy use, watt/sf lighting, plug loads, and thermal performance goals.

Determine Building Orientation & Configuration (A1.4)

In the high performance design process, the identification of basic constraints, goals, and footprint options are critical factors that have a major impact on the energy performance of the building design. The proper positioning of the building footprint can provide energy savings that far outweigh any other design decision that will be made during other activities in the process. Much as the orientation on the site greatly impacts the building performance, the configuration of the spaces within the building impacts energy systems requirements most through day lighting. An effective design understands the functional program such that the configuration, orientation, and functionality are all working together through systems integration.

Determine System Performance Requirements (A1.5)

Systems performance requirements that need to be considered during the definition phase of the design process include envelope performance (u & r-values for windows and thermal properties of the exterior walls), desired light design densities, and anticipated heating and cooling loads. This information should be utilized to develop a preliminary energy and day lighting computer model of the building.

Define Building Load (A1.6)

The creation of a building model allows for the first time in the process a determination of the anticipated building loads. During the energy optimization design process, this activity focuses on initially identifying anticipated building performance through basic computer simulations. General design criteria such as rough building shape, location and environmental conditions are applied to the model so as to provide an analysis tool which informs decision making in the early stages of design. The two main loads that should be determined at this time are the lighting and energy loads for the building.

7.3.4 Level II Design Model

Figure 7-9 shows the Level II Definition Model for the design activity of energy system design. It is during the design process that key detailed decisions are made regarding the energy systems of the building. Refinements to the initial building load developed during the definition phase are made with alternative systems investigated afterwards. Once the loads are minimized and optimum systems identified and selected, systems details are coordinated. It is during the design phase of the project, that the preliminary energy and day lighting models are utilized to refine and optimize the building design.

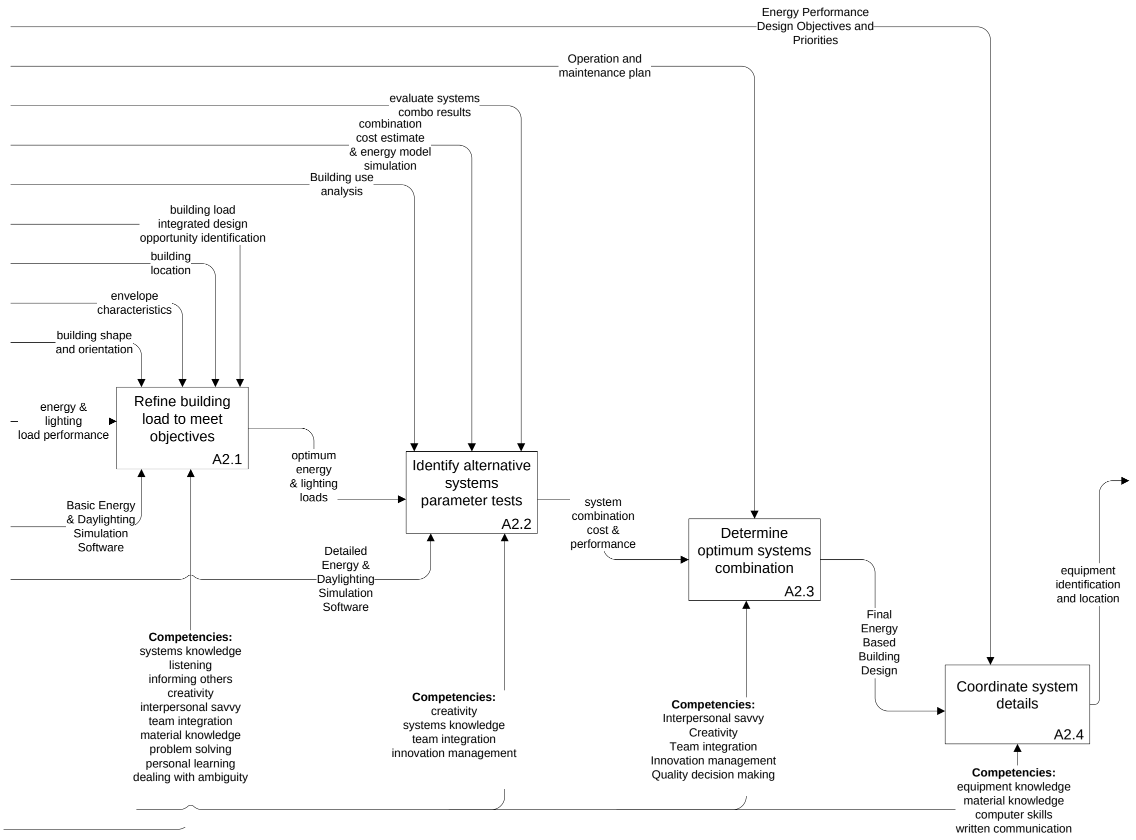


Figure 7-9: Level II DPM^{HP} - Design Activity (A1)

Refine Building Load to Meet Objectives (A2.1)

The final commitment in the definition phase of the design process was to the building load. In the design phase, the early stages are spent optimizing these loads to meet the energy performance objectives of the building team. Envelope characteristics, building shape and location are all considered in an effort to reduce the building load. The resulting commitment is optimized building energy and lighting loads allowing for the design of the mechanical, electrical and building envelope systems to begin.

Identify Alternative Systems Parameter Tests (A2.2)

Design evaluation simulation models are to be considered when building system integration is performed. The focal point of energy system integration is the consideration given to the building envelope and HVAC system relationships in an effort to reduce overall energy consumption while minimizing life cycle costs. Parameter tests include alternative wall types, design details that incorporate different day lighting strategies, the impact of different glazing material selections, HVAC systems selection, solar heat gain coefficients and visible light transmittance. Once alternative systems are identified, parameter tests are run in the simulation models and a cost estimate performed for each.

Determine Optimum Systems Combination (A2.3)

After initial systems are developed and their relationships identified, team members are to be informed of all energy system designs. Initial building energy operation results are shared and the impact of changing an individual system is discussed with each discipline prior to fine-tuning the design. Individual system combination designs are then evaluated and fine tuned during this activity in an effort to identify the optimum system components within the framework of the overall building design simulation model. Special attention must be paid to ensure that critical system relationships are not changed that will impact the overall building performance.

Once the individual systems combination analyses are completed, individual components of each systems combination are reviewed and considered last time for any possible optimum solutions not identified prior to the computer simulation and cost estimates. A commitment is made at this time by the team to the fine-tuned energy system design, and an energy system performance simulation is run for verification purposes. If the goals and objectives set forth in the definition phase of design are not satisfied, a decision whether or not to refine must be made prior to proceeding to the documentation phase of the design process.

Coordinate System Details (A2.4)

After a commitment is made to the fine-tuned energy system design, system details must be coordinated. Special attention must be paid as coordination decisions are made not to change the design intent and in turn impact the performance of the systems. The appropriate coordination of systems details increases the chance for an effective documentation phase because time is not spent designing the building. Once the systems details have been coordinated, pencils should not be lifted again by the design team, except to document the design. This commitment to coordinated systems details marks the end of the design phase and starts the documentation of the design.

7.3.5 Level II Documentation Model

Figure 7-10 shows the Level II Definition Model for the documentation activity of energy system design. This phase emphasizes the competencies possessed by those entities who document design for communication to the field. Of the utmost importance, in the detailed construction document development is the inclusion of design detailers that are knowledgeable in the construction of the key systems (building envelope, mechanical and electrical). The documentation phase of the design process begins with the determination of the appropriate documentation format. Consideration is given to the individuals that will be constructing the building and the most appropriate documentation format selected. Once this is determined, the detailed materials and equipment specifications are created and energy systems distribution, location and details developed.

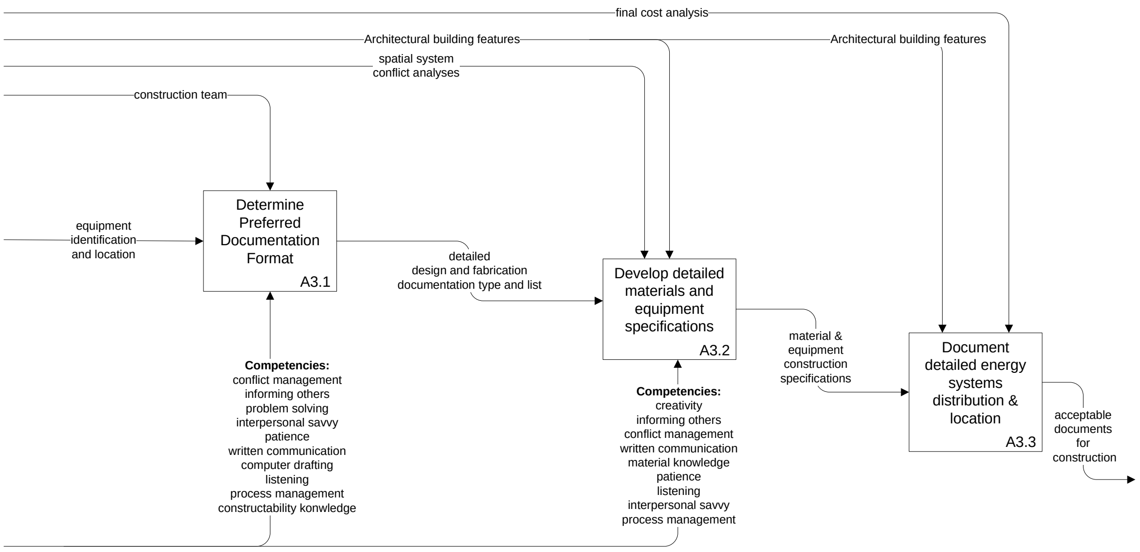


Figure 7-10: Level II DPM^{HP} - Documentation Activity (A2)

Determine Documentation Format (A3.1)

The appropriate determination of a documentation format relies heavily the knowledge and skills of the end user. The end user during design and construction is the construction team. Inclusion of these individuals during this decision is desired so that an appropriate format is selected. The more appropriate the format the better chance the team has of minimizing questions and the opportunity for changes to the design impacting the performance during construction.

Develop Detailed Materials and Equipment Specifications (A3.2)

During this phase, the coordinated systems details that were committed to in the final stages of the design are recorded for field use. Material identification lists and specifications are created. The level of detail that is included depends on the document format determination. The greater level of involvement that the builder had during the definition and design phases of the project will increase the likelihood that the design intent will be maintained during construction with decreased levels of detail presented in the materials and equipment specifications. Conversely, if the construction team had little or no involvement during the definition and design phases, the level of detail will need to be increased so as to convey an accurate representation of the design.

Document Detailed Energy Systems Distribution, Location and Details (A3.3)

The final step in the documentation phase of the design process for energy systems is the documentation of detailed energy systems distribution locations, equipment location and systems detailing. During this stage of the process, in addition to developing for field construction documents, any conflicts that were not identified during the design process must be resolved. A spatial system conflict analysis should be run for all distribution and heavy equipment locations. Interpersonal savvy and problem solving become two key competency requirements when conflicts arise. Once the documentation is complete, construction drawings have been completed and in conjunction with the material and equipment specifications a final cost estimate can be developed.

7.4 Comparison of IBPM and DDNM^{HP}

As part of this research, the DDNM^{HP} has been analyzed and compared in detail to the “Design Facility” model developed as part of the Integrated Building Process Model (IBPM) (Sanvido, et al., 1990) to test the Design Decision Network Modeling (DDNM) methodology. At the same time, the comparison demonstrates the relationship of the research to others in process modeling. The design model represents the activities necessary to produce a facility design from the point-of-view of a person outside the design organization. The DDNM^{HP} is a model that describes the key component of the design process for high performance buildings, the energy system design process from the point-of-view of the individuals whom are part of the of the design team both inside and outside of the primary design organization.

This comparison shows that the more detailed modeling of the energy system design closely matches the activities presented in the validated IBPM. While this close alignment does not validate the DDNM^{HP}, it does provide credibility to the information that is presented in the model. The In addition to the comparison of the two design process modeling techniques, case study events that support an IBPM event and/or DDNM^{HP} decision have been identified and associated with the event and/or decision.

Table 7-2: Process Model Comparison

DDNM^{HP} Decision	**IBPM Process**	**Case Study Event Examples**
Identify team competencies & assemble energy system design team		SALA-JN-06-01
Define Facility	**D.1) Understand Functional Requirements**	
Review facility program requirements & identify energy consumption project goals	D.11) Assimilate and analyze information	CAM-JT-01-02
Establish energy system project objectives and priorities	D.12) Establish project objectives	SALA-AT-01-01
Determine building orientation/configuration	D.13) Establish design parameters	CAM-JB-03-05
Define Facility	**D.2) Explore Concepts**	
Determine system performance requirements	D.21) Perform preliminary studies	AIHI-AF-03-01
	D.22) Prepare & develop concepts	
Determine building load	D.23) Coordinate concepts	CAM-JB-05-05
	D.24) Evaluate and select concepts	
Design Facility	**D.3) Develop systems schematics**	
Refine building load to meet objectives	D.31) Develop standard systems schemes	CAM-JB-05-01
Identify alternative systems parameter tests	D.32) Coordinate to find compatibilities	SALA-RR-05-01
	D.33) Develop integrated schematics	
Determine optimum systems combination	D.34) Evaluate & select schematics	AIHI-DR-05-02
Design Facility	**D.4) Develop Design**	
Coordinate system details	D.41) Perform systems development and layouts	AIHI-DR-06-02
	D.42) Perform studies and reviews	
	D.44) Acquire design approval	
Document Facility	**D.5) Communicate Design to Others**	
Determine documentation format	D.43) Develop outline specs, drawings, schedules	AIHI-DR-06-02
Develop detailed distribution location documentation	D.51) Develop post-design drawings	SALA-JS-03-06
Develop detailed materials and equipment specifications	D.52) Develop post-design specifications	
	D.53) Perform document reviews	
	D.54) Deliver post-design documents and acquire approval	

This analysis shows the direct relationship that exists between the new energy systems focused research that has been performed to the widely accepted more general design process modeling research of Sanvido. The results of this comparison are presented in Table 7-2. A detailed description of the IBPM activities can be found in work performed by Norton, (1989).

7.5 Summary

This chapter presented the three main parts of the research that led to the final Design Process Model for High Performance Buildings (DPM^{HP}) developed for utilization in step #2 of the evaluation of the engineering design process for high performance buildings (see Figure 7-1).

Once developed, the model was compared to an established design process methodology, developed with the same modeling technique as part of the Integrated Building Process Model (IBPM) research conducted by (Sanvido, et al., 1990). Key similarities as well as differences that have been identified for the general design process model (IBPM) and the more specialized design process model for high performance buildings (DPM^{HP}). New knowledge is presented for the design process of high performance buildings based on the process model comparison and case study data analysis in this chapter.

Chapter 8

Conclusion

8.1 Research Conclusions

This thesis addressed the need for an improved description of the design process for high performance buildings. The goal in the research has been to develop a methodology to evaluate continuously and improve the value, relationships, and timing of decisions in the design process for high performance buildings through a reduction in waste. This chapter first provides a summary of the research results. The results are then mapped against current knowledge in various research fields to identify the contributions from this research. Limitations to the research results are then discussed, and the chapter concludes with a discussion of promising areas for future research.

8.2 Research Results

The research developed six propositions and tested each for validity. The results support five of the six propositions identifed in Section 4.2. The results showed that:

1. Engineering the design process based on the desired functions of the building adds value to the design process,
2. The design process is a network of decisions producing commitments, connected by discipline specific analysis activities performed by design actors with associated competencies,
3. Changes to the sequencing and timing of key decisions, dictated by the building's desired functions can add value to the overall process.

4. Value is added to the design process when critical decisions that need to be made pull information and analyses required to reach an informed commitment, and
5. Realization of value generation from implementation of the integrated design process is dependent upon inclusion of key individual and team competencies.

The sixth proposition, “A process-based methodology to assess sequencing and timing of key decisions in the design process results in an improved design process based on value added/lost,” did not meet the requirements for validation set forth in Chapter 3 of the research and is therefore ommitted from the research findings. The main cause for the lack of validation is considered more a reflection of the inadequacy of the case study examples to evaluate the proposition than disproval of the proposition itself. This is because of the three cases selected for the research, only one implemented a process-based methodology at any point in the design process, and that project did not implement it throughout the entire design process. Therefore, evaluation of Proposition #6 was incomplete because of lacking evidence gathered from the case study projects that were selected.

In addition to the validation of the five research propositions, synthesis of the research findings has occurred in the form of an industry implementation tool. The Design Process Evaluation Model for High Performance Buidlings (DPEM^{HP}) has been presented in Section 4.2. This model was developed as a methodology to assess the key components of the design process as identified by the research in an effort to improve the design process through added value. Essentially, the development of the DPEM^{HP} was performed in response to the absence of a continuous process-based method in the case study projects. The five steps that make up the DPEM^{HP} are:

1. Determine the building’s desired function and form the team,
2. Develop a decision based design model,
3. Evaluate key decisions for value added based on timing and sequencing,

4. Identify information considerations needed for key decisions, and
5. Identify competency requirements for process implementation.

The five step evaluation process is iterative in nature and includes multiple reviews during the design process. The multiple reviews result in an approach that results in continuous value improvement of the design process for high performance buildings.

Influential Guiding Decisions and Guiding Requirements for High Performance Buildings

The following definition for high performance buildings has been developed for this research:

“A high-performance building is one that minimizes resource consumption while providing healthy and productive environments for the occupants and incurs the least possible life cycle costs while minimizing first time costs through systems integration.”

Industry practice along with case study findings from this research have shown that the system-based design approach utilized in the integrated design process for sustainable buildings is appropriate for the design of high performance buildings. This integrated process re-emphasizes prior design components as well as introduces new activities. A greater emphasis is placed on:

1. Increased interdisciplinary collaboration throughout the entire design process,
2. A system-focused approach to design decisions,
3. Appropriate sequencing of design decisions, and
4. Increased emphasis on individual’s who possess strong teamwork competencies.

New activities include:

1. Design charette to discuss specifically the high performance aspects of the facility design,
2. Energy model development and simulations to inform and aid in decision making throughout the design process,
3. Day lighting model development and simulation to inform and aid in decision making throughout the design process, and
4. Emphasis on integrated design opportunity identification.

These new activities combined with those issues that have heightened importance in the design process for high performance buildings result in a process that differs from that of conventional design. To address this change in the design process, a new decision-based Design Decision Network Model (DDNM^{HP}) that provides guidance for design teams engaging in the design of high performance buildings has been developed for the design of energy systems. The DDNM^{HP} has been developed for utilization in Step #2 of the initial iteration in the DPEM^{HP}.

8.3 Contributions to Knowledge

This research had five main objectives that were presented in detail in Chapter 1:

1. Identify current requirements in high performance building design,
2. Validate the decision-based design characterization of high performance building design,
3. Develop a methodology to assess the timing and sequencing of key decisions required to achieve a high performance building design process,
4. Provide a decision and competency based evaluation model that aids in the implementation of research findings into practice, and
5. Identify future research topics on high performance process delivery.

Through a rigorous case study research approach, all five of the objectives set forth have been achieved and several contributions to the body of knowledge related to design theory, process modeling, and integrated design theory have been identified. These include:

1. Development of a detailed evaluation model for the design process on high performance buildings – Design Process Evaluation Model for High Performance Buildings (DPEM^{HP}),
2. Development of an event-based case study approach and data collection instruments for evaluating design decisions, commitments, and information for value contributions on high performance buildings, and
3. Development of a detailed set of key value categories relevant in the design of high performance buildings to measure design process decisions and their impact on the design process.

8.4 Limitations

Two limitations of this research are the low number of case studies and the absence of rival theories in the case study data collection phase of the research. This research addresses the emerging field of high performance building design. As an emerging field, the number of applicable case study projects that are available and accessible to the researcher is currently limited. A design process database is currently being developed in conjunction with the Department of Energy and the Design Build Institute of America that will allow for future studies to be conducted on design process and competency requirements of the high performance design process. The development of this exploratory research will aid in the implementation of appropriate research into the field of high performance building design process in the future. As discussed in Chapter 3, rival theories were considered during the determination of event requirements for proposition validation; however, during the case study event identification, rival theories were not actively sought. This would require an in-depth research effort given the nature of the propositions and theories being tested.

8.5 Future Research

This research is exploratory in nature and has developed a context within which the design process for high performance buildings can be evaluated and discussed. Many different design process attributes (e.g. decisions, information, commitments, and competencies) have been considered for the first time in this research. As a result, several opportunities for further research have been identified. Recommendations for future research are presented in this section.

8.5.1 In-Depth Study of the High Performance Building Design Process

With the continued growth of sustainable building construction in the United States and the research that has been conducted in this study, the groundwork has been laid to conduct a larger study pertaining to the design process of high performance buildings. Specific issues that should be addressed would be the identification of the decisions and associated information that have the greatest impact on high performance building project success. A more in-depth case study approach can be utilized to develop an even higher level of detail for the Design Process Model for High Performance Buildings (DPM^{HP}). In addition to adding detail to the model, the continued growth of High Performance Buildings in the United States in the future will provide larger quantities of data that can for the first time, be used to test high performance building design processes developed in this research for statistical significance.

8.5.2 Testing of the DPEM^{HP} Relationship of Project Success to DPEM^{HP} Implementation

The DPEM^{HP} is a model supported by individual testing and validation of five propostions in this research; however, the associated impact of implementing the DPEM^{HP} has not been measured in the research conducted. Future research should set out to measure the impact of implementing the DPEM^{HP} approach on high performance projects. The value and waste definitions developed in the current research can act as guidance in quantifying the impact of the DPEM^{HP}.

8.5.3 Competency Inclusions as a Success Indicator

This research has determined competency requirements of the design process for high performance buildings. The impact of the presence or absence of specific competencies on each case study project has been determined through a value evaluation. Future research can investigate the relationship between project success and the presence of team competencies identified in the current research to be key components of the design team on high performance projects.

8.6 Summary

The general problem addressed in this thesis is the need for a better characterization of the design process for high performance buildings, with the research goal being to develop a strategy that provides design management and evaluation support for the high performance building design process. A summary of the research findings from three case study projects has been presented resulting in an initial characterization of the design process for high performance buildings (DPM^{HP}). A comparison of the model to a research standard design process model (IBPM) has been conducted. To aid in the realization of the research findings in the practice of high performance building design, an implementation tool (DPEM^{HP}) was developed.

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Appendix A

Glossary of Terms

Actors (Propositions #2 & 6): individuals that participate in the design process

Analysis (Propositions #2 & 5): checking the effects that proposed design actions have on the building project

Design Process Model for High Performance Buildings (DPM^{HP}):

Commitments (Propositions #2 & 5): obligation or responsibility for a future design action

Competencies (Propositions #6): an underlying characteristic of an actor (i.e. motive, trait, skill, knowledge) which results in effective and/or superior performance on a job

(Job) Competency: An underlying characteristic of an employee (i.e. motive, trait, skill, aspects of one's self-image, social role, or a body of knowledge) which results in effective and/or superior performance on a job (Boyatzis, 1982).

Competency Identification: The process of identifying job competencies (Rothwell and Lindholm, 1999).

Competency Model: The result of competency identification. It describes key characteristics that distinguish exemplary performers from fully-successful performers (Rothwell and Lindholm, 1999).

Competency Modeling*:* The process of writing out the results of competency identification by creating a narrative to describe the competencies (Rothwell and Lindholm, 1999).

Concurrent Engineering: the integration of the product design, development, manufacturing, and marketing processes.

Cross Functional Design Process Map for High Performance Buildings (CFDPM^{HP}): design management tool to assess how design processes are aligned with functional competencies distributed among project team members and aid in the appropriate competency involvement on high performance building design teams.

Decisions (Chapter 2): (1) a choice from among a set (either closed or open) of options, (2) an irrevocable allocation of resources.

Design Decisions (Propositions #2-5): accepting or rejecting a proposed design action

High Performance Building: A high-performance building is one that minimizes resource consumption while providing healthy and productive environments for the occupants and incurs the least possible life cycle operating costs.

Information (Propositions #2 & 5): knowledge acquired through analysis or experience

Integrated Definition Method (IDEF^0): a model that represents a process as a series of diagrams

(IDEF^0)Controls*:* Conditions or circumstances that govern the activities performed

(IDEF^0) Inputs: Information or objects required to perform activities

(IDEF^0)Mechanisms: Persons or devices that carry out the activity

(IDEF^0)Outputs: Information or objects that are created when an activity is performed

Integrated Design Opportunity: a strategy that reduces redundancies between systems in order to increase energy efficiency and reduce first time costs

Value (Propositions #3 & 5): actual transformation process of information core to the service that the end user is expecting. (Liker, 2004) (Hines and Taylor, 2000) (Womack and Jones, 1996)

Value-Adding Action (Propositions #3 & 5): Activity that efficiently converts information towards that which is required for a design inclusive of the desired building functions.

(Non)-Value Added but Essential: Decision, activity or process that is incidental but necessary work to produce a value added outcome. (Liker, 2004) (Hines and Taylor, 2000)

(Commitment Based) Value: consists of those decisions that generate information that correctly inform and support future decisions.

(Competency Based) Value: consists of the value generated by the presence and timing of key competency involvement

(Information) Value: measure of the level of value introduced to a decision based on the quality of the available information

(Decision Timing) Value: measures the balance between the value of ambiguity and the value of commitment when considering the timing of a decision

(Sequence) Value: actions, attributes, decisions or commitments that improve the design process through appropriate organization of design activities

(Time) Value: actions, attributes, decisions or commitments that improve the design process through duration reduction

Wasteful (non value-adding) Action (Propositions #3 & 5): Activity that takes time and/or resources but does not add relative worth or importance to the process.

(Overburdening) Waste: waste created by overburdening employees, tools, or equipment. Overburdening can result in immediate and long term quality problems by pushing people, tools, or equipment beyond natural limits. (Liker, 2004).

(Process Unevenness) Waste: waste introduced to the process by people being asked to do too much or to little based on the average volume of work or project requirements? (Liker, 2004) Information is delivered in a batch format and allowed to sit idle for extended periods of time?

Wicked Problems: ill-defined problem sets which are too complex to be solved by rational systematic processes

Appendix B

Competency Modeling

Language of Work Competency Identification Process

COMPETENCY IDENTIFICATION STEPS

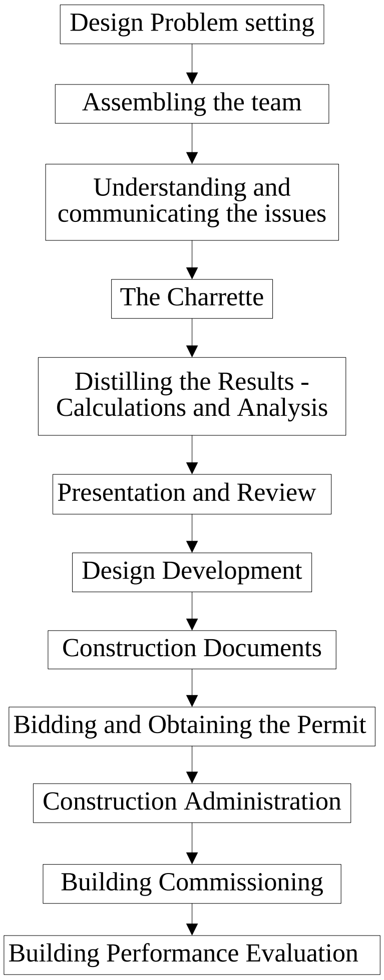
1. Define the Job Model
    a. Inputs
    b. Processes
    c. Outputs
    d. Consequences
    e. Feedback
    f. Conditions
2. Attach the Skills and Knowledge needed to perform the job to the Job Model
    a. Skill – is a learned capacity to successfully perform a task or activity with a specific outcome
    b. Knowledge – is the information or understanding needed to perform a task successfully
3. Identify Competencies from the Skills and Knowledge
4. Generate Competencies from the Following Critical Areas of Performance
    a. Attributes – a demonstrated cognitive or physical capacity to successfully perform a task with a wide range of possible outcomes (Marrelli 1998).
    b. Job Standards – level of proficiency that a job behavior should achieve
    c. Work support – various interventions and programs that organizations provide so that behavior and standards are achievable
    d. Human Relations – those attributes related to enabling others to get their work done, as well as avoiding things that inhibit work behaviors, standards and work support

Appendix C

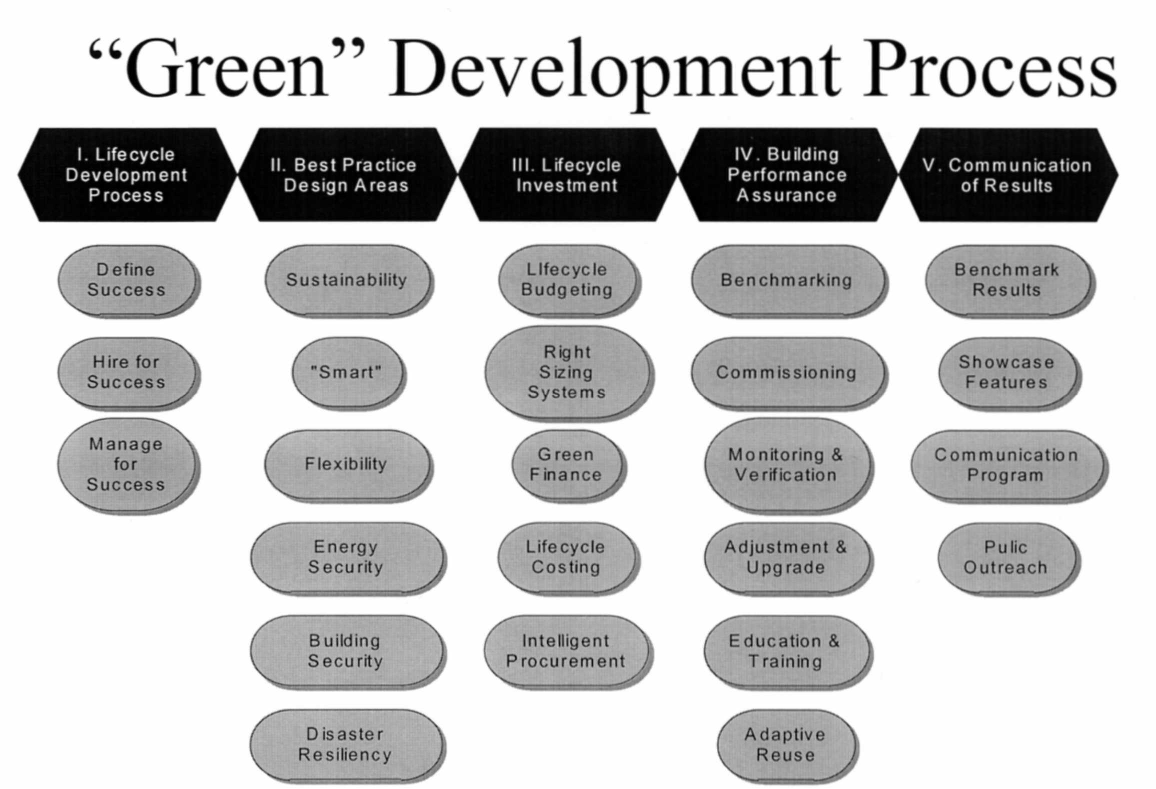
Existing Design Process Models

C.1 General Approach to the Integrated Design Process

General Approach to the Integrated Design Process
(adapted from Bill Reed, Natural Logic)



C.2 “Green” Development Process



“Green” Development Process

I. Lifecycle Development Process	II. Best Practice Design Areas	III. Lifecycle Investment	IV. Building Performance Assurance	V. Communication of Results
Define Success	Sustainability	LIfecycle Budgeting	Benchmarking	Benchmark Results
Hire for Success	"Smart"	Right Sizing Systems	Commissioning	Showcase Features
Manage for Success	Flexibility	Green Finance	Monitoring & Verification	Communication Program
	Energy Security	Lifecycle Costing	Adjustment & Upgrade	Pulic Outreach
	Building Security	Intelligent Procurement	Education & Training	
	Disaster Resiliency		Adaptive Reuse	

Appendix D

Case Study Questionnaire and Proposition Event Tracking Sheets

D.1 Letter of Introduction

CASE STUDY RESEARCH SUMMARY

The problem that I'm working on lies in the area of how the design process for buildings is managed. When I worked in the industry I was frustrated many times with the role I was asked to play in design management during the construction phase of the project. One of the things I found is that the way we describe the design process is pretty vague. Terms like conceptual, schematic, design development, 50% construction documents, and 90% construction documents are spoken but the meaning not always understood by all necessary parties.

I've also found when I look at the theories of design in the engineering field they do not apply to building design, or many times they do apply but are not used. The problem I am trying to address is the lack of definition for how the design process really happens. What I hope to do is come up with a way to better define the process and at the same time develop some tools that help to manage it. In order to improve and optimize the process this is where we need to start. To help focus my efforts, I have narrowed the scope to energy efficient buildings and the systems that have the greatest impact on the building's energy performance, like mechanical and electrical systems and the building envelope. Buildings that emphasize these same attributes as well as indoor air quality are considered to be high performance buildings, and you'll probably hear me use that term throughout our interview.

I’m talking to representatives from different projects trying to find examples of actions, decisions and activities that support or refute the perspective I’ve come up with to describe the design process. Without going into a lot of detail on the theory behind my characterization, it states that it is critical to understand when value is present in the process as well as how waste manifests itself in the design process. Any ***examples of decisions and activities during design*** that you can share with me that ***hurt*** your project or ***improved*** it at any level would be great. Those examples will help me determine if I’ve described the process effectively as well as help in developing tools to better manage the design process

D.2 Interview Tracking Form

Case Study Interview Agenda – Background Information

- Provide general information about my research
    - Exploring the process of designing high performance buildings in detail; interested in the who, what, why , and when of the integrated design process
- My background
    - Undergraduate degree in Architectural Engineering in 1996 from The Pennsylvania State University
    - Work experience includes 8 years with two large construction managers
    - Received Masters of Science in Civil Engineering from The University of Pittsburgh in 1999
    - Began my PhD studies at The Pennsylvania State University full-time January 2004
- Scope of Research

    - Determine if the development of a competency and process based methodology to evaluate the design process for high performance buildings eliminates waste and improves design team performance.
    - Develop a methodology to evaluate and improve the design process and team.
- Deliverable
    - Development of a theoretical decision based model for the design process
    - Creation of tools and methodology to continuously evaluate the energy system design process
    - Case study support of research question and propositions
- Research program and progress thus far
    - Collection of Existing Data – Integrated Design Roundtable facilitation, conference attendance (Greenbuild 2003 & 2004, CIB 2004, Green Building Alliance Conference 2004, PACE Roundtable and Seminar 2001-2004), literature reviews, , personal experiences pre-construction experiences with multiple LEED^{TM} projects, LEED^{TM} Accreditation, and miscellaneous interviews.
    - Theoretical Decision Based Design Model Development
    - High performance design continuous evaluation tool (DPEM^{HP} derived from the DPM^{HP})
    - Case study data collection method development

General Project Questions

PROJECT OVERVIEW QUESTIONS

- How Many gross square feet is the building? [BACKGROUND]
- What was the total cost of the building for which the design team was responsible or $/sf? [BACKGROUND]
- What type of contract was used for the design services? Construction services? [BACKGROUND]

- How many months were initially scheduled for design? Ultimately spent on design? Causes for difference? [BACKGROUND]
- How many months were initially scheduled for construction? Ultimately spent on construction? Causes for difference? [BACKGROUND]
- Are you pursuing LEED^{TM} accreditation? [BACKGROUND]
- How much does your design exceed ASHRAE 90.1-1999 (or equivalent) minimum energy performance requirements (LEED Energy & Atmosphere Credit 1.1)? [BACKGROUND]

PROJECT SUCCESS INDICATORS

- Going into the project what was your definition of success? [BACKGROUND]
- Was the project a success?
- Compared to other projects, how successful/unsuccessful was this one? [BACKGROUND] Rate on a scale of 1 to 5, 1 = Worst of Class, 3 = Average ‘as expected’ and 5 = Best of Class. [BACKGROUND]
- Was the design process successful? Rate on a scale of 1 to 5. [BACKGROUND]
- Was the project successful for your organization? Rate on a scale of 1 to 5. [BACKGROUND]

DESIGN TEAM QUESTIONS

- What participants made up the design team? [BACKGROUND]

Proposition #1 – The building design process should be engineered to a particular end by the building’s desired functions.

- Once the team was formed was a design goal clearly identified at the beginning of the project? What was it? [PROP. #1 & #5]
- Did you have a broad, meaningful purpose that all team members were committed to? [PROP. #1 & #5]

- What are the most important desired attributes of the final building design? [PROP #1]
- What impact did these desired attributes have on the way the design team developed the final design? [PROP #1]

ENERGY SYSTEM QUESTIONS

- What are the key cross-disciplinary interactions that took place during the design of the energy systems in which you were involved? [EXPLORATORY]
- What are the key cross-disciplinary interactions that took place during the design of the energy systems in which you weren't involved? [EXPLORATORY]
- Of the activities, tasks and processes dealing with energy systems during the design of your building, what would you consider to be the three most important when it comes to ensuring success at the end of the project? Did your design team effectively accomplish these tasks? [EXPLORATORY]

Proposition #2 – The design process is a network of decisions producing commitments, connected by discipline specific analysis activities and information, each performed by design actors with associated competencies.

- What were the key decisions that needed to be made during the design of the energy systems (i.e. mechanical, electrical, envelope) for the building? [PROP #2]

Write these down to re-visit in Proposition #3 questioning

- What information was desired in order for the team to commit to the key design decisions? [go to Proposition #4] [PROP #2]
- Were analyses performed in order to develop the information required as well as inform decision that needed to be made? [PROP #2]

Proposition #4 – Value is added to the design process when critical decisions that need to be made pull the information and analyses required to reach an informed commitment.

- What analyses were performed to inform the design? [PROP #4]
- Did you have all of the desired information available to base key decisions? If no, what information or analyses were missing? Why? [PROP #4]
- What impact did the missing information have on the design process? [PROP #4]
- Was a decision making process identified prior to encountering key commitments in the process? [PROP. #4]
- Did you receive the information needed to complete your design effectively? [PROP. #4]
- Did the individuals performing these analyses possess analysis specific skills and/or knowledge? What were they? [PROP #2 & #5]

Proposition #5 – Effective implementation of the improved design process (Proposition #3) is dependent upon inclusion of key individual and team competencies.

- When assembling the project team, how were the firms and individuals that performed design activities required for the building energy systems selected? [PROP. #5]
- Were the specific skills and knowledge these individuals possessed considered? [PROP. #5]
- Looking back on and during the design process, what skills or knowledge did the team possess that contributed positively to the process? Negatively? [PROP. #5]

- Looking back on and during the design process, what skills or knowledge did specific individuals possess that contributed positively to the process? Negatively? [PROP. #5]
- Were there changes to core team members throughout the process? When those changes occurred, what skills/knowledge were lost or gained with the new individual? [PROP. #5]

Proposition #3 – Changes to the sequencing and timing of key decisions, dictated by the building's desired functions, can add/detract value to the overall design process.

- Going back to the key decisions you identified earlier, at what stage in the design process (definition stage, design phase, or documentation phase) were each of the key decisions made? [PROP #3]
- If you had it to do over again, would you have made any of the decisions at a different time or in a different sequence? If yes, why? [PROP #3]
- Did you receive valid and timely information during the design process that enabled you to complete your design effectively? [PROP. #3]

Proposition #6 – Identification and development of a process based methodology to assess sequencing of key decisions in the design process results in an improved process.

- Does your firm have a standard design process that it follows on all projects? Was it implemented on this job? [PROP #6]
- Explain any up-front planning that was involved in defining the way the team would develop the design. [PROP #6]
- Were the key decisions that would need to be made discussed during this planning? [PROP #6]
- Was the approach to doing work was clear and shared, making use of all team members' skills? [PROP. #5 & #6]

Describe the design process that led to the energy system design (i.e. building envelope and MEP systems) for your building. {track on cross-functional competency matrix developed from $\mathrm{DPM}^{\mathrm{HP}}$} [PROP. #6]

Appendix E

Proposition #1 Event Tracking Table

S$^+$ - Positive Support; S$^-$ - Negative Support; C – Contradicts

(S)/(C)	Event
PROMOTE SUSTAINABLE AND HIGH PERFORMANCE DESIGN (CAM-NREL-01-01)	
S$^+$	**Building's desired function:** Advance the concept of High performance Buildings in the Commonwealth by providing a comfortable and productive work environment while minimizing its environmental impact. Energy consumption, cost and environmental impact were primary concerns for the project. **Resultant design process plan:** The team committed to a LEED^{TM} Gold rating on the project and established additional performance targets required for earning LEED^{TM} credits related to site issues, waster use, energy efficiency, materials and indoor air quality. The early phases of the design focused on building orientation, form and function requirements as dictated by the LEED^{TM} rating system requirements that were aligned with the targeted LEED^{TM} credits Pursuit of LEED^{TM} Gold rating is one factor that led to an integrated design process (see proposition #2).
REDUCE ENERGY USE (CAM-NREL-01-02)	
S$^+$	**Building's desired function:** Reduced building energy use. **Resultant design process plan:** Utilization of an integrated design approach and design process measures that help attain LEED^{TM} energy reduction points. Identification of integrated design opportunities was emphasized in the definition phase of the project and cross-disciplinary systems optimization continuously explored throughout the definition and design phases of the project.

REDUCE ENERGY CONSUMPTION (CAM-JM-01-01)	
S^+	**Building's desired function:** Reduced energy consumption through appropriate load determination and sizing of equipment **Resultant design process plan:** Typically a building like this from an air-conditioning standpoint would have more than enough capacity, every safety factors is included in every calculation and the result would be somewhere between 350-400sf/ton, that is pretty standard in classic design schemes. The desire to minimize energy use and loads led to an understanding of the how the building was being used. That is this is a building for field engineers that 4 out of 5 days of the week were going to be in the field. This allowed the design team to take some liberties in anticipated occupancies that normally wouldn't be taken. The owner's representative, who understood the usage of this building, was able to convey to the intended use with a certainty that allowed the design team to push the limits of design loads. The final design ended up with somewhere near 650sf/ton, which is considerably less capacity than a building of this size and type would normally have. The benefits were a significant reduction in the size of the entire mechanical system, including the loop field, so it paid off in reducing its own cost and probably pays off in performance in the long run as well. Other design measures that impacted the way we developed the final building design; included all team members' focus on the development of an appropriate light shelf design, the wall construction, and location of equipment.
DEVELOP A SUSTAINABLE DESIGN (CAM-JT-01-01)	
S^+	**Building's desired function:** Pursuit of a LEED^{TM} Gold Building rating with top attributes of the building including indoor air quality, reduced energy consumption, and utilization of photovoltaics. **Resultant design process plan:** These desired attributes impacted the design process as early as the negotiations of the lease and the design. The team developed a list of very specific attributes the project needed to meet from a design, performance and operations standpoint. This list of attributes resulted in performance requirements of the building that could not be met through conventional design techniques. The performance standards instigated the need for an integrated design process that focused on cross-disciplinary systems optimization.

<table>
<tr><th colspan="2">PROMOTE SUSTAINABLE AND HIGH PERFORMANCE DESIGN (CAM-JT-01-02)</th></tr>
<tr><td>S^+</td><td>Building’s desired function: Set sustainable design example for the commonwealth of PA. This was accomplished by acting as a model for future sustainable buildings in the commonwealth by setting a leadership position and demonstrating one can build green at the same cost as conventional design/construction.

Resultant design process plan: A clear definition of project goals were developed early in the design process and a team commitment reached to develop the design in an integrated manner. It was determined that the function of the building and its utilization were required. The project definition as the occupant and owner look at it must be well understood by the entire team and thought through and made available to the design professionals. How is the space going to work, people relationships, if you don’t have a good understanding of that you cannot begin to design the building? Cambria is really the building we built the GGGC video program around. The guidelines developed by the members of the design team ultimately became part of the performance standards for a Model Green Office Building Leasing Specification Space in PA (can be found on the DEP web-site).</td></tr>
<tr><th colspan="2">REDUCE ENERGY CONSUMPTION (CAM-JB-01-01)</th></tr>
<tr><td>S^+</td><td>Building’s desired function: Achieve approximately 50% energy savings

Resultant design process plan: The form (configuration and orientation) of the building was clearly driven by the need to accommodate daylighting in the design and reduce energy consumption through reduced building loads. Integration of the design process through design members all focusing on the optimization of systems made this desired project function attainable (see proposition #2 process model).</td></tr>
</table>

	IMPROVE INDOOR AIR QUALITY (CAM-JB-01-02)
S^-	**Building's desired function:** Provide indoor air quality that exceeds current standards **Resultant design process plan:** The desire to augment indoor air quality led to the selection of an under floor air plenum distribution system. The desire to reduce energy consumption led to the selection of an underground heat pump system. Coupling ground source heat pumps with under floor air plenum distribution had not been done before this building. These design decisions impacted how the design team developed the design in a major way. In addition, daylighting received heightened attention including building form, size, orientation, shading devices, glazing types, glazing areas, and sunshades. Many decisions were brought to the table as a function of trying to design the best daylighting with the knowledge available even though the right tools (daylighting model) were not available. The space feels right, it just doesn't perform well. The ambient (indirect fixtures) are tied to photocell sensors & dimming valves. When adequate foot candles are read at the work surface the lights are dimmed. This isn't occurring as much as anticipated during the design resulting in additional energy consumption due to additional light usage. This could have been eliminated by running lighting models during design and performing an analysis of the models.
	DEVELOP A SUSTAINABLE DESIGN (CAM-JB-01-04)
S^+	**Building's desired function:** Design a sustainable building that can be constructed within the confines of conventional construction costs. **Resultant design process plan:** The developer had a lease which created clear limits to the construction budget. Anytime the design team wanted to add a cost (sustainable or otherwise) they needed to find a means to reduce overall first time costs to match or exceed the additional cost. An example of this is apparent in the selection of high performance windows that added first time window costs but resulted in decreased mechanical system costs (CAM-NREL-03-03). This forced the design team to find integrated design solutions for the building. An example of an integrated design example is the analysis of the mechanical room location. A cost estimate determined that the overall building square footage could be increased by extending each end of the building to compensate for the space occupied by the mechanical room in the first floor core. The additional cost two extend the building's ends was exceeded by savings to the mechanical systems costs resulting in a net savings and a more efficient mechanical system.

<table>
<tr><td colspan="2">REDUCE ENERGY CONSUMPTION (CAM-JB-01-05)</td></tr>
<tr><td>S^+</td><td>Building's desired function: Significant reduction of 'on-grid' energy through the use of renewable energy consumption (15kW Photovoltaic array)

Resultant design process plan: Life-cycle cost analysis to justify 1st time cost increase through utilization of a sell-back agreement from Green Mountain Power resulting in a 5 year pay-back.</td></tr>
<tr><td colspan="2">REDUCE ENERGY CONSUMPTION (CAM-MS-01-01)</td></tr>
<tr><td>S^+</td><td>Building's desired function: Meet or exceed the DEP green specs resulting in an overall energy consumption reduction.

DEP specs on lighting levels were based on specifications from the 1970's, way over lit. The other component of success would be trying to find a way to cost effectively install a renewable energy system on the building.

Resultant design process plan: Almost everything that was thought of relative to design took into consideration the energy requirements because of the requirement to meet the building specifications. DEP specs on lighting levels were based on specifications from the 1970's resulting in way over lit spaces. We helped to develop the DEP Green Specs the project sought to meet or exceed. Reducing redundancies such as the lighting requirements helped achieve an overall energy reduction.</td></tr>
<tr><td colspan="2">DEVELOP A SUSTAINABLE DESIGN AND REDUCE ENERGY CONSUMPTION (AIHI-DR-01-01)</td></tr>
<tr><td>S^+</td><td>Building's desired function: A premium is placed on a healthy and energy efficient building design (i.e. material choices consider the environmental impact taking greatest advantage of the resources available and the building consumes less energy than set forth by code ASHRAE 90.1)

Resultant design process plan: Emphasis was placed early in the design process on building footprint and building envelope selection so that energy efficient design decisions could be made after appropriate analyzes. Willingness to pay more for appropriate materials introduced more material options to the design process resulting in a more difficult process due to increased information requiring heightened analysis prior to making final decisions.</td></tr>
</table>

<table>
<tr><th colspan="2">DESIGN FOR CONSTRUCTABILITY (AIHI-DR-01-02)</th></tr>
<tr><td>S^+</td><td>Building’s desired function: Design a building that is easily assembled, so as to enable the extensive use of volunteer labor

Resultant design process plan: Design efforts focused to incorporate materials that could be prefabricated and easily manually erected on site. An example is the selection of SIPS panels and their impact on the design process. The panels due to their favorable environmental characteristics were selected; however, the large size of the standard panels requires they be cut down in size to reduce the overall weight of single sections allowing manual labor to install. During the design, appropriate considerations of adjacent structural systems were required dictating close collaboration between the envelope designer, structural designer, and construction manager.</td></tr>
<tr><th colspan="2">REDUCE ENERGY CONSUMPTION– (AIHI-AF-01-01)</th></tr>
<tr><td>S^+</td><td>Building’s desired function: Develop an energy efficient building design. One that exceeds the standard performance requirements of ASHRAE 90.1.

Resultant design process plan: From a mechanical design process perspective, involvement early in the design process during the building envelope development is desired when energy consumption reduction is desired. On this project that is how the design process occurred. Decisions focused on simplicity of mechanical systems during selection to control cost, and control of mechanical systems aiming to keep things simple while making sure there is no opportunity for competition between heating and cooling systems creating energy system waste.</td></tr>
<tr><th colspan="2">DESIGN FOR CONSTRUCTABILITY – (AIHI-SW-01-01)</th></tr>
<tr><td>S^+</td><td>Building’s desired function: The use of volunteer labor results in the need to design a building that easily constructed. A 3-week construction schedule led to decisions that changed the way we design and construct the building.

Resultant design process plan: Building materials are selected during design entirely because they have been used in the past and proven to be easily constructed by volunteer labor. The fact that a crane is not on site, impacts the pitch of the roof, size of SIPS panels weight of trusses and the number of stories the building is designed to have (one).</td></tr>
</table>

DEVELOP A SUSTAINABLE DESIGN (SALA-AT-01-01)	
S^+	**Building's desired function:** Achieve low energy performance utilizing sustainable systems at the same time providing comfort to the building inhabitants. **Resultant design process plan:** The desire for low energy performance resulted in the recognition of a heightened importance of interdisciplinary design team coordination. An example of this is the conceptual design team's simultaneous utilization of computer models for daylighting and energy consumption analysis when developing the design. The mechanical, electrical and plumbing designers evaluated the daylighting study and computer models together during concept design and studied each system with the architecture in an effort to develop the optimum energy efficient design concept through effective utilization of day lighting. Specific items that were looked at include location of daylight sensors, different shading options for glazing, and solar paneling and how much light gets into the building.

PROMOTE SUSTAINABLE DESIGN AND HIGH PERFORMANCE DESIGN (SALA-JN-01-03)	
S^+	**Building's desired function:** Educate the building's occupants, design/construction management, and administrative individuals on sustainability by developing a 'non-granola' (integration of materials that does not resemble granola where each material assumes an independent identity instead of creating one building) sustainable building with a process that educates. **Resultant design process plan:** A design charette was conducted including individuals who desired to be educated, as well as members of the design team. In this meeting the building orientation and configuration was developed by the mechanical concept mechanical engineer. In addition to the design charette, pursuit of a LEED^{TM} Silver building and the design matrix that is part of the rating system added structure to the sustainable design process.

DEVELOP A SUSTAINABLE BUILDING (SALA-RR-01-01)	
S^-	**Building's desired function:** Develop a sustainable building design. **Resultant design process plan:** An internationally known design architect and engineer were hired for the definition phase of the project. The definition and design phase of the project began successfully but momentum and focus was lost as the project proceeded. A lot of this was due to the traditional mindset of the primary financial donor. His support for the sustainable faucets of the building was minimal. Also, the contract administrator/project architect was pushing during the documentation phase of the project to get the documents completed which resulted in use of standard design details and changes to the conceptual design resulting in the loss of sustainable building features.
PROMOTE SUSTAINABLE AND HIGH PERFORMANCE DESIGN (SALA-RR-01-02)	
S^+	**Building's desired function:** Utilize a design process that will educate the faculty and staff that are unfamiliar with sustainable design on the main components of the special design. **Resultant design process plan:** Two information sessions were conducted with faculty and staff, led by the concept architect and assisted by the owners design and construction management group, with the sole purpose being to educate the individuals that attended and answer questions regarding sustainable design.

Appendix F

Proposition #3 Event Tracking Table

S^+ - Positive Support; S^- - Negative Support; C – Contradicts

(S)/(C)	Event
	DESIGN CONCEPT CHANGES (CAM-NREL-03-01)
S^+	**Timing of key decision:** Definition Phase (early schematic) **Value impact:** Significant modifications to the developer's original design concept resulted in minor rework. The original plan (developed from initial assumptions aimed at lowering first time construction costs) envisioned a relatively square box with a flat roof and an orientation that responded to the road along the property's edge in order to maximize curb appeal. The resulting building was poorly oriented with limited ability to capture solar energy and daylight. Changes occurred to optimize solar orientation and preserve wetlands on the property. Further design modifications enabled the project to protect all pre-existing wetlands while meeting programmatic requirements. The early timing of the changes resulted in the ability of the design team to re-shift focus to an elongated building with minimal to no additional design costs.
	DAYLIGHTING & ACCOUSTICAL PERFORMANCE (CAM-NREL-03-02)
S^+	**Timing of key decision:** Definition Phase (late schematic/early design development) **Value impact:** The roofing system originally envisioned comprised a steel deck supported by steel bar joists, with rigid insulation sandwiched between the deck and a standing-seam metal roof. The final design consisted of a series of products: wood/steel trusses, reflective roof decking composed of 100% post consumer recycled waste paper along with a nail base, and recycled steel shingles. This roof assembly, which exceeded the performance criteria, provided additional environmental benefits, and offered better acoustical properties. This was deemed to be the appropriate time because it eliminated a component of cost estimating and allowed sizing of one system component; by making the decisions as early as it was made, it eliminated any rework on all other systems because at the time we were still reducing building loads not sizing and designing mechanical systems.

<table>
<tr><th colspan="2">BUILDING FENESTRATION CONSIDERATIONS (CAM-NREL-03-03)</th></tr>
<tr><td>S^+</td><td>Timing of key decision: Design Phase (see also CAM-MS-05-01)

Value impact: Two options were considered for the building fenestration design consisting of a combination of punched opening windows and storefront windows. The first option was to use radiative or convective perimeter heating. This approach had an initial cost estimate of $25,000. The second option was to use triple-glazed windows and attempt to eliminate the perimeter heating system. A system cost analysis demonstrated that low-e, tripled glazed windows would exceed the performance requirements, allow for the elimination of perimeter heating, contribute to energy savings via reduced heat gain and loss loads, and in turn, allow for HVAC system downsizing. The windows would cost ~$15,000 more but the systems approach considered in its entirety resulted in a first time cost reduction.</td></tr>
<tr><th colspan="2">DAYLIGHTING & LIGHTING DESIGN (CAM-NREL-03-04)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: Documentation Phase

Value impact: The initial lighting design (as developed by the lighting vendor) called for a lighting power density of .82 W/ft^2. Subsequent refinement of the lighting system resulted in a final design LPD of .75 W/ft^2, not including task lighting. This design modification was made late in the overall process when a consulting engineer reviewed the design that was developed by the lighting vendor. The result was changes that required drawing modifications and additional coordination during construction.</td></tr>
<tr><th colspan="2">EXTERIOR LIGHTING DESIGN (CAM-NREL-03-05)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: Documentation Phase

Value impact: The original parking lot design (as developed by the lighting vendor) contained 14 cut-off fixtures with 400-W standard metal halide lamps on nine poles. Additional analysis during the documentation phase of the project resulted in a final design of five cut-off fixtures with 400-W pulse start metal halide lamps each mounted on its own pole. The final design met the illumination recommendations of the Illuminating Engineering Society of North America (IESNA 2000) while reducing the first cost by more than $3,600 and reducing the energy costs by more than $1,800 per year compared to the original design. The result to the process was changes to the design documents and additional coordination.</td></tr>
</table>

<table>
<tr><th colspan="2">HEATING. VENTALITION, AIR CONDITIONING SYSTEMS (CAM-NREL-03-06)</th></tr>
<tr><td>S^+</td><td>Timing of key decision: Design Phase
Value impact: Initial HVAC design focused on the use of gas a boiler/absorption air conditioner system. It was determined the building and its loads were too small for this type of equipment. Recommendations by the contractor centered on packaged rooftop units, but they did not meet all of the performance criteria. A DOE-2 energy model was used as input for a life-cycle costing analysis, which included first cost, maintenance cost, energy cost, and depreciation over a 25-year time frame. The ground-source heat pump system was shown to save more than $500,000 over the 25-year period. The timing of this decision led to no problems as they relate to the design process.</td></tr>
<tr><th colspan="2">MECHANICAL ROOM LOCATION SELECTION (CAM-NREL-03-07)</th></tr>
<tr><td>S^+</td><td>Timing of key decision: Definition Phase (early design development)
Value impact: The architect originally predetermined that the location of the mechanical equipment would be in the penthouse. The optimum solution was determined to be two rooms located on the first floor, one in each wing of the building. The savings to the project resulting from the elimination of the mechanical penthouse and the reduced duct and pipe runs (including increased cost of adding space to the building to accommodate desire for equal leasable space), were estimated at $40,000. In addition, HVAC system performance was enhanced due to the minimal turns in the duct system, and maintenance personnel have easier access to the mechanical equipment.</td></tr>
<tr><th colspan="2">ENERGY EFFICIENT DESIGN CHANGES (CAM-NREL-03-10)</th></tr>
<tr><td>S^+</td><td>Timing of key decision: Definition Phase
Value impact: The building configuration was elongated along an east-west axis to gain better solar access and optimize daylight penetration into the building. The rooflines were sloped in order to allow the use of north- and south-facing clerestory windows on the second floor for daylighting, which also provided an angled surface for mounting PV panels. Light shelves were added on the south side of the first floor to help direct some daylight deeper into the office space. To improve the success of the daylighting, the second floor plan was designed to place the large open office spaces adjacent to exterior walls and locate enclosed offices in the center of the building rather than at the perimeter. As a result, these private offices do not block access to daylight, and the vast majority of occupants are afforded access to this daylight and views.</td></tr>
</table>

	BUIDLING CONFIGURATION (OFFICES) (CAM-JB-03-01)
S^+	**Timing of key decision:** Definition Phase (early in schematic design) **Value impact:** The final design includes a fundamental layout that runs all of the enclosed private offices in the interior of the building down the core so that 90% of the employees have access to daylighting in larger open areas. That was determined very early in schematic design that was absolutely the appropriate time. The timing of the decision allowed us to engage in fine-tuning of the configuration strategy early in the process so that we didn’t have to waste resources analyzing a box configuration. This allowed us to meet our energy performance goals in the end with no added resource use due to a mistimed decision during design
	LOAD REDUCTION (CAM-JB-03-02)
S^+	**Timing of key decision:** Define Phase (Late schematic and early design development) **Value impact:** Before we began to think about determining what our HVAC supply and distribution systems were, we did everything we could to reduce the loads first, that has everything to do with orientation, lighting, configuration, once you get your loads reduced. Then it was time to think about what the best system was supply and distribution wise to accommodate the determined load. Furthermore, how much of that load might be able to be accommodated with renewable energy was evaluated. Annual solar exposure and wind velocities become important. It is important to note on the Cambria project at this point we did not evaluate wind loads because technology for micro-turbines was not available. The complexity of the building will have an impact on the appropriate timing and duration of this event. For example, a laboratory or hospital would require a longer time to look at the process loads, from an identification standpoint as well as a minimization/reduction standpoint. By first reducing loads, building envelope commitments can be made prior to addressing mechanical systems fixing one of the two key variables in energy systems design.

PARAMETER TESTS (CAM-JB-03-03)	
S^{+}	**Timing of key decision:** Define (early design development late schematic) **Value impact:** Early design development/late schematic a series of parameter tests were run, that tested different r & u values, daylighting strategies and different glazing in the building energy model. We performed tests on multiple HVAC systems on Cambria. You should consider at least two different systems testing the fundamentals (i.e. air vs. water) modeling performance of the different system components. Once the models are developed you can compare the performance of each. Then once a series of individual component test runs were made, it was time to run a bunch of energy model simulations as a series of consolidated runs by looking at different combinations of energy efficiency measures to find the one or two that have the best system performance. At this point a cost estimate for each system you are testing was developed. Performing the cost and performance evaluations of the models at this time allows for a final system to be selected prior to detailed design taking place, minimizing the likelihood of redesign.
BUILDING MECHANICAL ROOM RELOCATION (CAM-JB-03-04)	
S^{+}	**Timing of key decision:** Definition Phase (early design development) **Value impact:** An additional design solution was discovered during a design meeting on the mechanical systems with the architect, mechanical engineer, mechanical contractor, energy modeler, developer and lessee. Inefficiencies within the mechanical system caused by the mechanical room penthouse location were alleviated by relocation the mechanical room to the first floor.
BUILDING ORIENTATION (CAM-JB-03-05)	
S^{+}	**Timing of key decision:** Definition Phase (early schematic) **Value impact:** The initial developer based design of the building was a box. The most efficient way to house the open office system and the center core was analyzed and the building shape was determined. The orientation is not divorced from configuration, note a fairly long linear building on a E-W axis, so its aspect ratio E-W to N-S is fairly low, much longer N-S elevations, with virtually no fenestration on E-W at all. This orientation and shape optimizes the natural solar gains available to the building. No design work had been completed beyond the concept of the building prior to the change resulting in no identifiable re-work.

<table>
<tr><td colspan="2">ELIMINATION OF PENTHOUSE MECHANCIAL ROOM (CAM-JM-03-01)</td></tr>
<tr><td>S^-</td><td>Timing of key decision: Design Phase (early design development)
Value impact: Elimination of the penthouse mechanical room occurred early in the design development; if it had occurred earlier people would have changed their minds and we wouldn’t have wasted a lot of time.</td></tr>
<tr><td colspan="2">MECHANICAL ROOM LOCATION (CAM-JT-03-01)</td></tr>
<tr><td>S^+</td><td>Timing of key decision: Design Phase (early design development)
Value impact: The meeting that the mechanical room was located in was extremely critical. I was there for every one of their meetings. Things did not happen and then they came to me and I only got what they wanted me to hear.</td></tr>
<tr><td colspan="2">BUILDING FOOTPRINT DECISION TIMING (AIHI-DR-03-01)</td></tr>
<tr><td>S^-</td><td>Timing of key decision: Late completion of the building footprint design resulted in delays to subsequent activities including LEED^{TM} evaluation team analysis, mechanical design and controls design, utility relocation plan.
Value impact: Information was not available for future decisions due to time and resource constraints that made additional analyses including energy modeling prohibitive.</td></tr>
<tr><td colspan="2">DEFINTION PHASE DESIGN COMMUNICATION (AIHI-DR-03-02)</td></tr>
<tr><td>S^-</td><td>Timing of key decision: An inability during conceptual design to solicit feedback regarding building function by the concept designer resulted in the necessity to develop alternative concept designs approximately 3 months later than planned
Value impact: A delay to final construction document preparation and completion resulting in decreased opportunities for analyses as the basis for informed documentation and construction decisions.</td></tr>
<tr><td colspan="2">INCOMPLETE DESIGN DOCUMENTATION (AIHI-DR-03-03)</td></tr>
<tr><td>S^-</td><td>Timing of key decision: Inability to complete 120% construction documents (shop drawing quality construction documents)
Value impact: Decreased detailed construction planning and sequencing, lost opportunity for organization and planning of volunteers, and inability to solicit and receive competitive bids for material and sub contracts in advance of the construction process as planned. A specific example is with the window systems.</td></tr>
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<table>
<tr><th colspan="2">ENERGY SYSTEM DECISION TIMING (AIHI-DR-03-04)</th></tr>
<tr><td>S^-</td><td>Sequencing of key decision: It was determined the energy systems (radiant floor heating and evaporative cooling) were selected later than desired, after recognizing the advantages of their use in the region could potentially outweigh prior decisions that had been made for related building systems.

Value impact: This approach would eliminate the risk of designing a building that could not accommodate the natural mechanical system. This approach allows the building to form around the energy systems.</td></tr>
<tr><th colspan="2">CONTROL SELECTION (AIHI-DR-03-05)</th></tr>
<tr><td>S^-</td><td>Sequencing of key decision: The control logic was selected by volunteers prior to the completion of the mechanical design

Value impact: It was determined after the mechanical system was designed that the control system selected by student volunteers was inappropriate requiring a redesign of the system. Due to time constraints, the design needed to be subcontracted to a professional causing re-work as well as a missed opportunity to effectively utilize volunteer support</td></tr>
<tr><th colspan="2">FINAL CONTROLS SYSTEM SELECTION (AIHI-RX-03-01)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: Early in the documentation phase (80-90% CD’s)

Value impact: The initial controls system selected in the design phase of the project was one that could not be serviced by anyone within a 600 mile radius of the site. After the building foundation had been designed, the controls contractor who had provided general input on the control logic was brought into the design process to aid in the selection of the controls system. The system that had been selected by the mechanical engineer was changed to a digital system that can be maintained locally and monitored remotely over the internet.</td></tr>
</table>

<table>
<tr><th colspan="2">CONTROL WIRE ROUTING (AIHI-RX-03-02)</th></tr>
<tr><td>S^+</td><td>Timing of key decision: Early in the documentation phase (80-90% CD’s)

Value impact: The primary design team had intended to run the controls wire in the building slab. The controls designer explained the benefits of running the wire overhead. Running the wire overhead would eliminate the need for conduit and provide easier access for installation and maintenance. VAV boxes were utilized so the wire had to reach each box whether it was roughed in the slab or overhead. By running the wire overhead the connections could be made to the VAV boxes and one drop made to the radiant floor control valves that were also part of the system. A cost savings of $1,500 was realized by making this change.</td></tr>
<tr><th colspan="2">CONTROLS DESIGN (AIHI-RX-03-03)</th></tr>
<tr><td>S^+</td><td>Timing of key decision: Early in the documentation phase (80-90% CD’s)

Value impact: The key is to discuss the wiring before the foundations have begun. As a control contractor, most of the time the sequences are taken from ASHRAE or something already proven. Before the final construction documents were produced, the mechanical engineer brought the drawings over and the control contractor red-lined them resulting in a commitment to the design.</td></tr>
<tr><th colspan="2">TIMELY INCORPORATION OF ENERGY SYSTEM DESIGN RECOMMENDATIONS (AIHI-AF-03-01)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: Elimination of building envelope penetrations in the form of doors and windows was recommended after the initial review of the building design by the mechanical engineer to the design manager. Changes were incorporated into the documents, however, no communication existed between the mechanical engineer and envelope designer, and no feedback indicating the changes were going to be incorporated until the next version of drawings were transmitted to the mechanical engineer. The mechanical engineer did not see how the decisions were arrived at.

Waste impact: The missing communication between the mechanical engineer and team during recommendations consideration resulted in increases in mechanical design time and lost opportunities to consider his expertise in final decisions. Examples of wasted efforts due to inappropriate information flow include 2 re-designs of the ductwork systems in order coordinate with structural trusses. Ultimate impact: 50% increase in mechanical design time.</td></tr>
</table>

<table>
<tr><th colspan="2">UNTIMELY TRUSS SELECTION (AIHI-AF-03-02)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: After the mechanical distribution systems had been initially designed and sized (late in design phase for the mechanical systems)
Value impact: Not knowing how the structure (trusses) were going to take shape, forced the mechanical engineer to change the design of the ductwork systems at least three times. Certain parameters were assumed based on prior experiences, however for this building it was decided they could not be met, therefore the design needed to be changed.</td></tr>
<tr><th colspan="2">UTILITY RELOCATION DESIGN (AIHI-SW-03-01)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: Utilities relocation was intense. It needed to be made a year ago. All of the parties should have been represented (University, utilities, design team) at a meeting at that time. We should have been more attentive to the cost and made the college aware of it. Knowing this was a utility driven design, it would have been optimum to answer those questions earlier. Contributing to the problems was the fact that the design team was 2,000 miles away, speak a different language.
Value impact: That would have helped everybody and taken pressure off of other design phases. You could have potentially designed other things different.</td></tr>
<tr><th colspan="2">SIPS PANEL SIZE SELECTION (AIHI-SW-03-02)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: Dragging out the commitment of the SIPS panel sizes impacted the project by having more time put towards figuring that out which took away from other aspects (i.e. utility relocation). One of the reasons the decision was dragged out is because we were unable to get accurate costs to inform the decision.
Value impact: There are some things that were not drawn fully so they are figured out in the field. Skylight system framing for the skylights to go in was never drawn. This could result in improper installation. [NOTE: At the time of the interview the installation had not yet been completed and inspected.]</td></tr>
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<table>
<tr><th colspan="2">TIMING OF COMPETENCY INVOLVEMENT (AIHI-SW-03-03)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: In the fall, after UW concluded its piece, I drew a schematic redesign essentially changing positions of things. Dimensionable drawings that ended up how it was primarily designed. At that point it was very rationale. 8’-0” OC center spacing, things that were repeatable. It is easier to draw and build this way. A new faculty member joined us who interested in working on the project who had worked on a day care center before. He added the fin that gave a much more interesting profile and it improved daylighting intake and create a stack effect for natural ventilation. Look at SIPS panels in a new rhythm and windows floated in the wall more.

Value impact: Redesign was needed because the appropriate design competency was not present during the conceptual design development.</td></tr>
<tr><th colspan="2">DESIGN DEVELOPMENT DOCUMENTATION (AIHI-SW-03-04)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: The final window design commitment was when windows were being ordered. The project really went from schematic to shops. I did drawings when I did details, but true DD drawings are when you work out problems. I did that for critical details, but to be honest none of it was looked at carefully by anyone other than me. The reason we didn’t have a DD phase other than what I drew was because everyone’s efforts were focused elsewhere, the utilities and foundation. Design responsibility was separated in three directions. Project manager – technical systems. architect – details of the polygala system. I was looking at the other stuff. We didn’t give ourselves the time to get on the same page to work those details out.

Value impact: Coordination between adjacent systems was not completed until installation occurred. This leads to the possibility (and realization) that systems are not installed as intended by the design team. Either a design intent is ultimately not realized or changes need to occur in the field to meet the design intent.</td></tr>
</table>

<table>
<tr><th colspan="2">FOUNDATION SYSTEM DESIGN (AIHI-SW-03-05)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: Facilitation of communication was not apparent during the design process. There is information I would receive in a meeting that I hadn’t heard earlier.
The foundation system is something that was talked about and discussed that I wasn’t part of. It was one thing and changed to ICF’s and it wasn’t coordinated with SIPS panels. They couldn’t sit on ICF’s. The OSB of a SIPS panel has to sit on something hard to support the skin. The day of the pour I asked if anyone had confirmed this, and it had to be changed on the spot. That is a fault of the design that resulted in field waste. What would have helped us is if we would have documented our ideas and we had all seen it. It wasn’t until the wall section was drawn (1 week before the pour) that I caught the potential issue and raised it. It was assumed that didn’t matter and why waste time thinking about it.
Value impact: It’s not a big issue just something that if we would have gotten a DD set of drawings done it would have saved everyone a lot of time and effort. That is an example of negative interdisciplinary information sharing. Once you get it on paper it helps to facilitate the appropriate information sharing.</td></tr>
<tr><th colspan="2">SYSTEM COORDINATION (AIHI-SW-03-06)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: The foundations were drawn earlier but our division of labor led to me turning it over to the project manager and the late change to ICF’s is where the problem was introduced. It was thought through for straw bale, but not the SIPS. The impact it ultimately had was that 2-3 days the week before volunteers were going to show up. I noticed it on a Tuesday and they were going to pour on a Thursday.
Value impact: The decision was made to pour it conventionally and the pour failed, formwork blew out and if everything had been designed beforehand everyone would have had the time to do it to do it right and the blowout could have been prevented. An already stressful project added stress and duration because leveling the concrete and anchor bolts didn’t work. Everyone would have caught it on the drawings.</td></tr>
</table>

CONCEPTUAL DESIGN REVIEW (AIHI-SW-03-07)	
S^-	**Timing of key decision:** The conceptual phase designer completed the building design without soliciting feedback (analysis) from the owner and other design team members throughout the design phase prior to a final decision regarding the design being made. **Value impact:** A delay to final construction document preparation resulted because the rest of the design team subsequently ended up changing the design to meet the goals and mission of the owner. Input from the conceptual designer was totally lost at this point as well as the time that was spent reworking the conceptual design that had been developed.
TRANSITION OF MEP DESIGN RESPONSIBILITY (SALA-JN-03-01)	
S^-	**Timing of key decision:** End of definition phase (end of schematic) **Value impact:** Transition of design responsibilities was limited to 2 meetings to discuss the design as it had been completed to date. The resulting impact was the second designer left with a schematic design that they didn't know why the decisions had been made and a lot of time was spent by the lead architect providing information on the history and background of the mechanical design.
TRANISTION OF LANSCAPE DESIGN RESPONSIBILITY (SALA-JN-03-02)	
S^+	**Timing of key decision:** Middle of definition phase though completion of definition phase (mid-schematic through schematic completion) **Value impact:** Value was added through increased understanding of the design scheme by overlapping design responsibilities of both designers during design scheme generation. The second designer understood the decisions that led to the design and limited to no time were spent educating the second designer on the history and background of the mechanical design.

TRANSITION OF STRUCTURAL DESIGN RESPONSIBILTY (SALA-JN-03-03)	
S^{-}	**Timing of key decision:** End of definition phase (end of schematic) **Value impact:** The first structural engineer developed the design scheme with analysis software that considered assumptions that were not able to be transferred to the software utilized by second engineering firm. Rework was introduced to the process in the form of time spent learning new computer software by the second engineer and waste in the form of running models in a software that was unable to translate assumptions in the same manner as the initial software.
INITIAL STRUCUTRAL LOAD DESIGN GUIDELINES (SALA-JN-03-04)	
S^{-}	**Timing of key decision:** Early definition phase (conceptual phase). Minimum load requirements as allowed by code at an aesthetically important portion of the building were the basis of structural design by the concept structural engineer. After the design responsibilities were handed off to the second structural engineer and architect of record, it was determined the minimum loads allowed by code were unacceptable to the designers of record. **Value impact:** Structural member size recalculations were performed late in the design phase (design development) and into the documentation phase (construction documents) of the projects. The result was no changes to member sizes, only the waste created by the need for a recalculation.

HEATING SYSTEM DESIGN (SALA-JN-03-05)	
S^-	**Timing of key decision:** During the definition phase of the project (concept and schematic), energy models were developed and aided in the selection of mechanical systems. **Value impact:** A heat recovery system was recommended at the time but not modeled extensively. It was ultimately determined early in the documentation phase (early in construction documents) that the heat recovery system would result in monetary savings. Early in the documentation phase it was decided a heat recovery system should be utilized in the building. This resulted in modifications to the design through implementation of renovation type systems because of the constraints placed on the heating system by space constraints dictated by the extent of architectural system design completed at the time. Re-analysis of the heating system was performed early in the documentation phase resulting in rework to the original system. The final system was not optimally designed due to constraints do adjacent systems that were not flexible (i.e. wall and equipment layout).
MECHANICAL SYSTEM SELECTION (SALA-JS-03-01)	
S^-	**Timing of key decision:** Define (Beginning schematic design) through design (75% design development) **Value impact:** The owner requested we include a specialized HVAC system developed by a University professor. The architect had limited locations they wanted to use the system (2 classrooms), when the professor found out it would be in only two rooms, he said don't bother putting it in. Multiple modifications to the design occurred and a lot of time was invested by the mechanical engineer for a design that didn't get included. When it was taken out of the building, a standard VAV system took its place. If it had been decided not to proceed with this idea earlier in the process, it would have saved time and money on the part of the mechanical engineer.

<table>
<tr><th colspan="2">ENERGY RECOVERY MECHANICAL SYSTEM DESIGN (SALA-JS-03-02)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: Design (75-80% design)
Value impact: Additional work took place with regard to the energy recovery in the HVAC system. The conceptual mechanical engineer didn’t include any energy recovery in the initial concept and during design development the succeeding mechanical engineer made some comments that it would be worth considering in a green building. At this time, it was determined no further action would be taken regarding this design. Around 75-80% complete, the energy modeler ran another model and determined the project could save money by including the energy recovery. Space was needed to add pumps and coils and this caused a lot of design rework because the decision was made too late in the design process. It should have occurred in the beginning because of the heightened importance that was placed on energy savings in the beginning and the desire to pursue LEED^{TM} energy points. It impacted us both by adding additional cost and time spent.</td></tr>
<tr><th colspan="2">AIR LOUVER LOCATION (SALA-JS-03-03)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: Documentation (75% Construction Documents)
Value impact: The initial model/rendering of the building left substantial HVAC louvers off of the ends of the building. They were shown on the drawings from the time that design development mechanical engineer got involved in the project (beginning design development). At the 75% design submission, the PM for the owner asked what the louvers were. They weren’t shown on the original rendering that had been approved by the company president so they couldn’t go in where they were shown. The mechanical designer considered many alternative locations and designs before selecting the final alternative location. The mechanical engineer suffered in extra time and money spent whereas nobody else on the design team had substantial additional waste.</td></tr>
</table>

CLASSROOM COMMITTEE DESIGN CHANGES (SALA-JS-03-04)	
S^-	**Timing of key decision:** End of Documentation Phase (95% construction documents) **Value impact:** Classroom modifications occurred after the classroom committee reviewed the drawings at 95% construction document phase. Walls were moved and spaces were rotated 90 degrees in the classroom spaces that resulted in lights, ductwork/diffusers and fire protection system changes. During construction (50-60% complete), the same committee came back again with similar changes to the same spaces. The changes impacted the mechanical engineer on a financial basis including redrawing and redesign. During construction subcontractor coordination change order requests were presented by the contractor for more conduit run and additional number of outlets. I don't know if it slowed construction down, but it impacted it because there was additional work.
NOTIFICATION OF CHANGES (SALA-JS-03-05)	
S^-	**Timing of key decision:** Documentation Phase **Value impact:** The mechanical engineer requested additional services at the end of the project design. In retrospect, that was too late. They weren't paid for all changes because they weren't submitted when they happened.
MECHANICAL SYSTEM SPACE COORDINATION (SALA-JS-03-06)	
S^+	**Timing of key decision:** Documentation Phase (construction documents) **Value impact:** A key decision in the process is making sure there is enough space for all of the mechanical equipment and the distribution systems (shafts). It creates a lot of heartaches if it is determined at the end of the project there isn't enough space. The coordination of equipment and distribution systems need to be made at the end of design development but could be made as late as 65% CD's. Delaying the decision saves redesign time if it turns out a bulkhead needs to be put in. It was done in 40-50% CD's on the case study project and that was fine. There was some tweaking that occurred during construction, but no ceilings needed to be lowered during construction because there was not enough space and changes were minimal.

<table>
<tr><th colspan="2">HEATING/COOLING SYSTEM CONSIDERATION (SALA-AT-03-01)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: Midway through the definition phase (late in schematic design)
Value impact: A study into the utilization of passive ventilation was conducted. Specifically looking at panels on the roof and ventilation air passing through those panels and fed directly into the raised floor system (similar to hot water heating). The system ended up being very invasive to the building (not enough space to place it). It was decided during the completion of schematic not to go forward with it. If the system had been considered earlier in the definition process, the architecture of the building could have been modified to accommodate the system size, however, as the process dictated, the architectural design had been developed to the point were changes would have created excessive cost and time. (It was also determined that there would be technical issues created due to the climate and space use in the building with temperatures rising too fast for the system to accommodate)</td></tr>
<tr><th colspan="2">ARCHITECT RESPONSIBILITY TRANSITION (SALA-RR-03-01)</th></tr>
<tr><td>S^-</td><td>Timing of key decision: Integration of the architectural responsibilities from the concept architect to the contract administrator occurred from day 1 of design through the middle of design phase (middle of design development). The transfer did not carry into the documentation phase (construction documents) of the project.
Value impact: The result was an improper transfer of documents from the concept architect to the contract administrator resulting in redesign efforts.</td></tr>
</table>

Appendix G

Proposition #4 Event Tracking Table

S^+ - Positive Support; S^- - Negative Support; C – Contradicts

(S)/(C)	Event
BUILDING SYSTEMS SELECTION: **Building fenestration (CAM-NREL-05-01)**	
S^+	**Critical decision:** Building fenestration system selection. **Information required:** Primary information that was needed and developed to inform the decision of which fenestration system to include in the design is energy system performance analysis, cost analysis and window performance attributes. Two options were considered in order to comply with the project's performance requirements for interior glazing surface temperatures. The first was a radiative or convective perimeter heating. This approach resulted in an initial cost of $25,000. The second option was to use triple-glazed windows and attempt to eliminate the perimeter heating system. To select the appropriate window system, an analysis was performed to identify the overall performance of each system, and the impact on various systems (including HVAC sizes and distribution) each would have. It was determined that low-e, triple glazed windows would exceed the performance requirements, allow for the elimination of the perimeter heating system, contribute energy savings via reduced heat gain and loss loads, and in turn allow for HVAC system downsizing. **Value:** An integrated solution was developed that resulted in less first time cost as well as life cycle cost savings.

BUILDING CONFIGURATION/ORIENTATION DETERMINATION: **Mechanical room location determination (CAM-NREL-05-02)**	
	Critical decision: Location of the mechanical room **Information required:** Understanding the coordination of distribution piping, ductwork, etc. from the mechanical room throughout the building. Performance of different distribution systems and the cost of each alternative mechanical room location option. **Value:** It was determined locating the mechanical room on the first floor in the core would provide a more efficient energy system. This, however, would decrease the total square footage of leasable space. To accommodate the request to maintain the same leasable space, the architect added 1.5 ft to 2.0 ft to the west and east ends of the building. The savings to the project resulting from the elimination of the mechanical penthouse and the reduced duct and pipe runs (including the cost of adding space to the building) were estimated at $40,000. In addition, HVAC system performance was enhanced due to the minimal turns in the duct system and maintenance personnel have easier access to the mechanical equipment.
BUILDING CONFIGURATION AND ORIENTATION: **Elongated building shape vs. box (CAM-NREL-05-03)**	
S$^+$	**Critical Decision:** Building shape and orientation on-site **Information Required:** Building functional use including occupants, occupancy times and intended use. True solar north identification and accurate site plans identifying existing conditions and anticipated future conditions. **Value impact:** Significant modifications to the developer's original design concept resulted in minor rework. The original plan (developed from initial assumptions aimed at lowering first time construction costs) envisioned a relatively square box with a flat roof and an orientation that responded to the road along the property's edge in order to maximize curb appeal. The resulting building was poorly oriented with limited ability to capture solar energy and daylight. Changes occurred to optimize solar orientation and preserve wetlands on the property. Further design modifications enabled the project to protect all pre-existing wetlands while meeting programmatic requirements. The early timing of the changes resulted in the ability of the design team to re-shift focus to an elongated building with minimal to no additional design costs.

<table>
<tr><th colspan="2">BUILDING ENERGY LOAD DETERMINATION/MINIMIZATION:
Building load refinement (CAM-JB-05-01)</th></tr>
<tr><td>S^+</td><td>Critical decision: Systems integration selection

Information required: It was determined the information required for systems integration included a site plan with true solar North, an understanding of the functional program (including occupancy such that the configuration, orientation, and functionality are all working together. Additional important information to achieve systems integration opportunities include preliminary energy models with assumptions for u & r-values walls, roofs, windows and that can give you a pretty good sense of where you are headed. A series of refinements follow. At this point what we are trying to do is engage as many strategies as possible to reduce the loads on the building - lighting, heating and cooling and for that matter water consumption. On the case study building.

Value: An appropriately configured and oriented building was designed through an integrated systems approach resulting in anticipated energy savings ~50% above ASHRAE 90.1 standards. By having the information available to base the design upon, a thorough exploration of design opportunities occurred resulting in an energy efficient final design.</td></tr>
<tr><th colspan="2">BUILDING SYSTEM SELECTION:
Heating system design (CAM-JB-05-02)</th></tr>
<tr><td>S^+</td><td>Critical decision: Selection of heating system.

Information required: Another parameter test that was run is not sizing primary supply system for peak capacity, but rather for average or better than average capacity. For those peak loads install a supplementary boiler if heating is the driving peak load. For instance never size a ground source heat pump for maximum capacity but add a supplemental device for 7-8 days a year. This could be a high efficiency gas fired boiler or oversized hot water heater with a bypass into the heating loop. This is the kind of stuff that should be considered in design development. Loads have already been limited and now it is a matter of optimizing your system.

Value: Identifying average heating load requirements in lieu of maximum loads allows for the appropriate sizing of the heat pump. Minimizing excess waste that would be introduced to the building design if maximum loads were utilized.</td></tr>
</table>

BUIDLING SYSTEM SELECTION: Fenestration design (CAM-JB-05-03)	
S^-	**Critical decision:** Storefront fenestration design **Information required:** Primary information that was needed and developed to inform the decision of which fenestration system to include in the design is energy system performance analysis, cost analysis and window performance attributes. During the documentation phase of the project head, jamb and sill details were required, but not provided. **Waste:** An example of a key decision that pulled information from the design team both positively and negatively is the selection of the windows. The positive aspect was the way triple-e windows were selected to develop an integrated design solution with respect to the building energy systems (CAM-NREL-05-02). The negative side of things is the resultant information that was not developed for the construction phase of the project. At the time, only one manufacturer could provide a product that had thermally broken frames that met the performance requirements of the design. They were experiencing manufacturing and design issues during design and could not supply the frame details (head, sill and jamb) prior to construction. This complication was manifested by the fact that insulated concrete forms (ICF's) were utilized in storefront locations creating a new combination of products. These details ultimately needed to be solved in the field.
INTEGRATED DESIGN SOLUTION SELECTION: Modeling to inform daylighting design (CAM-JB-05-04)	
S^-	**Critical decision:** Daylighting design selection **Information required:** Daylighting was not designed very well on the building. At the time we had no access/familiarity with daylighting tools (computer simulation). A simplified approach (LEED^{TM} 2% guideline) was utilized, but it did not result in an effective daylighting strategy from an energy standpoint. **Waste:** A lot of daylighting is present in the building, but the impact on energy savings is minimal and disappointing.

<table>
<tr><td colspan="2">BUILDING ENERGY LOAD DETERMINIZATION/MINIMIZATION:
Building performance determination (CAM-JB-05-05)</td></tr>
<tr><td>S^+</td><td>Critical decision: Building load performance optimization
Information required: Annual solar exposure, wind velocities, building orientation, configuration, lighting, and computer model.
Value: Before we began to think about determining what our HVAC supply and distribution systems were going to be, we did everything we could to reduce the loads first, that has everything to do with orientation, lighting, configuration, once you get your loads reduced. Then it was time to think about what the best system was supply and distribution wise to accommodate the determined load. Furthermore, how much of that load might be able to be accommodated with renewable energy was evaluated. Annual solar exposure and wind velocities become important. It is important to note on the Cambria project at this point we did not evaluate wind loads because technology for micro-turbines was not available. The complexity of the building will have an impact on the appropriate timing and duration of this event, however the fundamental information required to perform the analysis and make the decision will remain the same. For example, a laboratory or hospital would require a longer time to look at the process loads, from an identification standpoint as well as a minimization/reduction standpoint, but the process loads still need to be determined and provided so that a proper decision can be made on the building load. On this project we met our energy performance goals large in part to the fact that we had the information needed to make accurate decisions regarding the anticipated building loads and related energy performance.</td></tr>
<tr><td colspan="2">BUILDING ENERGY LOAD DETERMINATION/MINIMIZATION:
Building utilization (CAM-JT-05-02)</td></tr>
<tr><td>S^+</td><td>Critical decision: Building use
Information required: Information on occupancy times and number of people was provided by the owner. The facility is available 24/7 and has to have the capability of being operated 24/7, but the reality is that it is not occupied 24/7.
Value: The realization that the building would not be occupied 24/7 decreased the building load allowing the downsizing of HVAC systems resulting in less first costs.</td></tr>
</table>

INTEGRATED DESIGN SOLUTION SELECTION: **Modeling to inform daylighting design (CAM-MS-05-01)**	
S^-	**Critical decision:** Daylighting design selection **Information required:** The daylighting is not working in the building currently, a big reason is because we didn't have *daylight computer modeling* during the design. The architect followed the art of the science, the problem wasn't that the design was poor; the problem was that the system wasn't analyzed to optimize it. Nothing was done to analyze daylighting on the project beyond the rudimentary LEED^{TM} calculation. This analysis was performed for the LEED^{TM} Credit. What should have been done is running some *daylight modeling software or a physical model*, they would have told us a lot about how the system would perform, looking back on it, it isn't difficult to see what should have been analyzed. The punched window openings on the north and south side have a head height only a couple of feet above partition height, so you get almost no depth penetration of the sun. You should run these at the schematic phase with a rough conceptual idea of the building including *orientation, reflectance assumptions, access to sky-dome, overhangs,* general information like that. The other thing that is obvious after looking at it and thinking about it is that the windows in the clerestory aren't large enough; a computer simulation would have told us that in the schematic phase. **Waste:** Had modeling been performed and the analysis incorporated into the design, it would have improved energy performance by increasing daylight reducing lighting requirements. Right now there isn't enough light to affect the dimming system. Not having enough light long enough results in no dimming occurring. This results in the lights consuming more energy than they should.

BUILDING SYSTEM SELECTION: **Heating system design (CAM-JM-05-01)**	
S^+	**Critical decision:** Selection of heating system. **Information required:** A ground source heat pump should always be sized for average or better than average capacity. Never size a ground source heat pump for maximum capacity but add a supplemental device for 7-8 days a year. Understanding the nature of the loads is critical so that we didn't result in a grossly under/oversized loop field. For instance, I was brought in to look at a laundry mat in Georgia that had huge loads, the nature of the 20 ton loads weren't understood resulting in a grossly undersized loop field. Average capacity must be understood, you cannot design to maximum loads like some other systems. **Value:** Identifying average heating load requirements in lieu of maximum loads allows for the appropriate sizing of the heat pump. Minimizing excess waste that would be introduced to the building design if maximum loads were utilized.
BUILDING SYSTEMS SELECTION: **Control logic selection (AIHI-DR-05-01)**	
S^-	**Critical decision:** Control logic selected/designed prior to mechanical design completion. **Information required:** Mechanical design. **Waste:** The mechanical design was delayed leading to additional cost to contract in the form of professional mechanical and controls engineering in lieu of volunteer engineering because the construction schedule and volunteer labor availability did not allow for volunteer design after the delays.
BUILDING SYSTEM SELECTION: **Mechanical system (AIHI-DR-05-02)**	
S^+	**Critical decision:** Selection of the mechanical systems (energy efficiency as a desired building function). Radiant floor heat and evaporative cooling systems ultimately selected due to their wide range of operating efficiency. **Information required:** The systems selection were made after preliminary energy and day-lighting models were developed for the building region **Value:** The final selections were supported by appropriate energy performance data produced by effective analyses.

MATERIAL SELECTION: Sustainable material considerations (AIHI-DR-05-03)	
S^+	**Critical decision:** Selection of environmentally friendly materials (desired building function utilization of material resources that minimized environmental impact). **Information required:** *Sustainable materials identification* accomplished through attendance at USGBC Greenbuild 2004 Exhibition. **Value:** A compilation of materials identified was used to develop a ‘kit of materials’ to be considered during the design in lieu of “force fitting” materials into the building to achieve LEED^{TM} Gold Rating.
BUILDING SYSTEMS SELECTION: Building envelope design (AIHI-DR-05-04)	
S^-	**Critical decision:** Timely information was not provided for the translucent building envelope design resulting in delays in the energy modeling and façade detailing. **Information required:** Alternative translucent envelope material properties and resulting insulating performance ratings. **Waste:** The impact has been costly because skilled labor will now be used to install the systems because appropriate time is not available to plan for a volunteer installation. In addition to the added cost, the building performance potentially is impacted because the delay forced a misinformed decision (due to missing analyses) to use a system that allows high levels of day-lighting at much lower insulating values.
BUILDING SYSTEMS SELECTION: Building footprint design (AIHI-DR-05-05)	
S^-	**Critical decision:** Multiple systems selection (mechanical design and utilities design selection) **Information required:** Building footprint design finalization **Waste:** Late completion of the building footprint design resulted in delays to subsequent activities including LEED^{TM} evaluation team analysis, mechanical design and controls design, utility relocation plan. Information was not available for future decisions due to time and resource constraints that made additional analyses including detailed energy modeling prohibitive.

<table>
<tr><td colspan="2">BUILDING CONFIGURATION/ORIENTATION DETERMINATION:
Definition phase decisions (AIHI-DR-03-02)</td></tr>
<tr><td>S^-</td><td>Critical decision: Building orientation and configuration selection
Information required: An inability during conceptual design to solicit feedback regarding building function by the concept designer resulted in the necessity to develop alternative concept designs approximately 3 months later than planned
Waste: A delay to the originally planned final construction document preparation and completion resulting in decreased opportunities for analyses as the basis for informed documentation and construction decisions in order to complete design to allow construction to proceed.</td></tr>
<tr><td colspan="2">BUILDING SYSTEMS SELECTION:
Energy efficient systems research (AIHI-AF-05-01)</td></tr>
<tr><td>S^-</td><td>Critical decision: Selection of an energy efficient mechanical system.
Information required: Consideration of multiple systems identified by students and researched by student teams.
Waste: After reviewing the systems researched with the mechanical engineer, it was clear that those investigated were not practical for the building being considered. The up-front direction given in this exercise was inappropriate leading the misguided allocation of resources.</td></tr>
<tr><td colspan="2">BUILDING SYSTEMS SELECTION:
Controls information (AIHI-RX-05-01)</td></tr>
<tr><td>S^+</td><td>Critical decision: Selection of controls system
Information required: Understanding of the system and what the engineer is trying to accomplish with the system. Specifically the types of fans, air handling units, heating and cooling equipment (ceiling or in-slab), and the objectives of the building performance.
Value: All of the information needed to make decisions regarding the controls system selection and design was made available either in the drawings or through conversations with the mechanical engineer or project manager.</td></tr>
</table>

BUILDING SYSTEMS SELECTION: **Utility relocation (AIHI-SW-05-01)**	
S^-	**Critical decision:** Utilities relocation design was intense. It needed to be made a year ago. All of the parties should have been represented (University, utilities, design team) at a meeting at that time. We could have designed other things differently if this issue had been resolved. Knowing this was a utility driven design, it would have been optimum to answer those questions earlier. **Information required:** *Cost of relocating utilities* and the *work required* to do so. That would have helped everybody and taken pressure off of other design phases. Instead, the team could not decide on an appropriate course of actions to take regarding utilities relocation resulting in continuous delays. **Waste:** Design efforts (time and resources) spent on the utility relocation late in the design process instead of developing, coordinating and completing the design of the building
BUILDING SYSTEMS SELECTION: **SIPS panels size selection (AIHI-SW-05-02)**	
S^-	**Critical decision:** Building envelope design decision **Information required:** Dragging out the commitment of the SIPS panel sizes impacted the project by having more time put towards figuring that out which took away from other aspects (i.e. utility relocation). One of the reasons the decision was dragged out is because we were unable to get ***accurate costs*** to inform the decision. **Waste:** There are some things that were not drawn fully so they are figured out in the field. Skylight system framing for the skylights to go in was never drawn. This could result in improper installation. [NOTE: At the time of the interview the installation had not yet been completed and inspected.]

<table>
<tr><td colspan="2">BUILDING SYSTEMS SELECTION:
System coordination (AIHI-SW-05-03)</td></tr>
<tr><td>S^-</td><td>Critical decision: Foundation system detailed coordination and documentation determination

Information required: Compatibility of adjacent systems (foundation & building envelope)

Value: The foundations were drawn early but our design team’s division of labor led to me turning it over to the project manager (who also acted as the structural engineer) and a late change to ICF’s is where the problem was introduced. It was thought through for straw bale, but not the SIPS. The impact it ultimately had was that 2-3 days the week before volunteers were going to show up. I noticed it on a Tuesday and they were going to pour on a Thursday. The decision was made to pour it conventionally and the pour failed, formwork blew out and if everything had been designed beforehand everyone would have had the time to do it to do it right and the blowout could have been prevented. An already stressful project added stress and duration because leveling the concrete and anchor bolts didn’t work. Everyone would have caught it on the drawings.</td></tr>
<tr><td colspan="2">BUILDING CONFIGURATION/ORIENTATION DETERMINATION:
Daylight shading requirements (SALA-AT-05-01)</td></tr>
<tr><td>S^+</td><td>Critical decision: Determination of shading requirements for the building

Information required: Orientation and height of the building, site characteristics (water tower & trees), window characteristics, spacing and room layouts inside of the building, sun behavior in the region considered, climatic issues, and a computer model of the building.

Value: All of the information that was required for the shading design was made readily available to the MEP designers in the definition phase of the project when it was requested. This allowed for an accurate computer model to be created and different options applied to the model and results analyzed before completing the design. Systems considered include light shelves, vertical fins to the light shelves, operable shades, and offset lights. The natural shading created by the trees also played a large factor in the amount of natural light reaching the building.</td></tr>
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<table>
<tr><th colspan="2">BUILDING ENERGY LOAD DETERMINATION/MINIMIZATION:
Building load (SALA-AT-05-02)</th></tr>
<tr><td>S^+</td><td>Critical decision: Anticipated building load selection
Information required: Building properties and building use. Detailed items include schedules of operation, occupant times for all spaces, building components from a fabric performance perspective, glazing properties, wall properties, building mass, building orientation, envelope properties.
Value: Building use and properties were made available to the mechanical designer in a timely manner allowing for the completion of a building design that will achieve ~40% energy savings above ASHRAE 90.1.</td></tr>
<tr><th colspan="2">BUILDING SYSTEMS SELECTION:
Heat recovery mechanical system design (SALA-JS-05-01)</th></tr>
<tr><td>S^-</td><td>Critical decision: Energy recovery system design determination
Information required: Energy model, space requirements, and performance analysis
Waste: Additional work took place with regard to the energy recovery in the HVAC system. The conceptual mechanical engineer didn’t include any energy recovery in the initial concept and during design development the succeeding mechanical engineer made some comments that it would be worth considering in a green building. At this time, it was determined no further action would be taken regarding this design. Around 75-80% complete, the energy modeler ran another model and determined the project could save money by including the energy recovery. Space was needed to add pumps and coils and this caused a lot of design rework because the decision was made too late in the design process. It should have occurred in the beginning because of the heightened importance that was placed on energy savings in the beginning and the desire to pursue LEED^{TM} energy points. It impacted us both by adding additional cost and time spent.</td></tr>
</table>

<table>
<tr><th colspan="2">BUILDING SYSTEMS SELECTION:
Heat recovery mechanical system design (SALA-JN-05-01)</th></tr>
<tr><td>S^-</td><td>Critical decision: Heat system selection
Information required: Building energy model including a heat recovery system in the design
Waste: The model including heat recovery was not developed until early in the documentation phase of the project this resulted in the implementation of a renovation type mechanical heat recovery system due to space constraints resulting in a system that is less efficient than a new construction system could be (albeit better than no heat recovery system)</td></tr>
<tr><th colspan="2">BUILDING SYSTEMS SELECTION:
Designer coordination (SALA-JN-05-02)</th></tr>
<tr><td>S^+</td><td>Critical decision: Heating system selection
Information required: New designer evaluating the current design and considering alternative designs specifically a heat recovery system
Value: More efficient system designed including heat recovery</td></tr>
<tr><th colspan="2">BUILDING SYSTEM SELECTION:
Raised floor system design (SALA-JN-05-03)</th></tr>
<tr><td>S^+</td><td>Critical decision: Selection of areas to receive under floor air distribution systems
Information required: Benefit cost-analysis of the raised floor by intended space use.
Value: The studio spaces were selected for under floor distribution because it is desired they would be flexible and easily reconfigured many times over the lifetime of the building. In order to design a flexible space cost effectively, it was determined power and data connections to work stations need to be easily relocated. The raised floor system allows this to be done with a plug and play system. Because flexibility is a requirement of the space and a raised floor system is the most efficient way to achieve this in the studios, a significant premium is not being paid for the HVAC under floor distribution system. So the studios were designed to trap hot air high and allow the cold air to stratify down low resulting in an energy efficient and more comfortable air distribution system.</td></tr>
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<table>
<tr><th colspan="2">BUILDING SYSTEMS SELECTION:
Heating system design (SALA-JN-05-04)</th></tr>
<tr><td>S^-</td><td>**Critical decision:** Heat recovery system design
Information required: Energy models.
Waste: A heat recovery system was recommended at the time but not modeled extensively. It was ultimately determined early in the documentation phase (early in construction documents) that the heat recovery system would result in monetary savings. Early in the documentation phase it was decided a heat recovery system should be utilized in the building. This resulted in modifications to the design through implementation of renovation type systems because of the constraints placed on the heating system by space constraints dictated by the extent of architectural system design completed at the time. Re-analysis of the heating system was performed early in the documentation phase resulting in rework to the original system. The final system was not optimally designed due to constraints do adjacent systems that were not flexible (i.e. wall and equipment layout).</td></tr>
<tr><th colspan="2">BUILDING SYSEMS SELECTION:
Daylight modeling (SALA-RR-05-01)</th></tr>
<tr><td>S^+</td><td>**Critical decision:** Building façade property/material selection
Information required: Daylight model
Value: The model determined that there was too much glass on the north face of the building that would result in heightened levels of glare. This was modified to reduce the amount and location of the glass to reduce glare in the early definition phase.</td></tr>
</table>

Appendix H

Proposition #5 Event Tracking Table

S^+ - Positive Support; S^- - Negative Support; C – Contradicts

<table>
<tr><th>(S)/(C)</th><th>Event</th></tr>
<tr><td colspan="2">FUNCTIONAL/TECHNICAL SKILL:
Detailed material & constructability knowledge (CAM-NREL-06-01)</td></tr>
<tr><td>S^+</td><td>The contractor suggested the use of insulated concrete forms (ICF) for the majority of the exterior wall construction. They had used them on a previous project and found them to save labor and time compared to other wall constructions.</td></tr>
<tr><td colspan="2">TIMELY DECISION MAKING & DEALING WITH AMBIGUITY:
Decision making/analysis time (CAM-NREL-06-02)</td></tr>
<tr><td>S^-</td><td>The design was developed so quickly that there was not enough time to fully evaluate design options. Construction began before some systems were fully designed, which limited the options that could be considered having a negative impact on systems integration. An example is the design of the storefront fenestration system. At the time, only one manufacturer could provide a product that had thermally broken frames that met the performance requirements of the design. They were experiencing manufacturing and design issues during design and could not supply the frame details (head, sill and jamb) prior to construction. This complication was manifested by the fact that insulated concrete forms (ICF’s) were utilized in storefront locations creating a new combination of products. These details ultimately needed to be solved in the field.</td></tr>
<tr><td colspan="2">TEAM INTEGRATION & FUNCTIONAL/TECHNICAL SKILL:
Heating system experience/team integration (CAM-NREL-06-03)</td></tr>
<tr><td>S^+</td><td>A ground source heat pump was selected for the heating system. The use of an experienced ground-source heat pump system designer combined with integrated design solutions, contributed to keeping the cost of the system within an affordable range. Collaboration between the mechanical designer, heat pump expert and architect produced optimized building systems resulting in significant load reductions. Key ingredients include building orientation, augmented thermal envelope, lower LPD, and thermal energy recovery. The result was cooling load reductions ~50% and total project cost reductions of ~$60,000.</td></tr>
</table>

PROBLEM SOLVING, TEAM INTEGRATION & FUNCTIONAL TECHNICAL SKILL: Mechanical expertise (CAM-NREL-06-04)	
S$^+$	An additional integrated design solution was discovered during a design meeting on the mechanical systems with the architect, mechanical engineer, mechanical contractor, energy modeler, developer, and lessee in attendance. The meeting began with a discussion about how to coordinate the installation of the piping, ductwork, etc. from the penthouse out into the building. The architect realized the inefficiencies caused by the penthouse location and asked the mechanical designer where the mechanical space would optimally be located to reduce installation costs and simplify design. The optimum solution was determined to be a division of the central mechanical space into two rooms, each located on the first floor, one in each wing of the building in its core.
FUNCTIONAL/TECHNICAL SKILL & INFORMING OTHERS: Energy model development & simulation (CAM-NREL-06-05)	
S$^+$	Specialty computer simulators were hired during the design and after design during performance evaluation to track the energy performance of the building. Hourly energy simulations with the DOE-2 were used during design. Energy simulation formed a significant part of the HVAC analysis, which resulted in the selection of ground-source heat pump system. This analysis used a simplified building model for the purposes of comparing HVAC systems. A more detailed model was created and used to validate and measure the results of design decisions (the detailed model was not used as a design tool) and was called the Design Building Model.
PROBLEM SOLVING, INTERPERSONAL SAVVY, LISTENING & PERSONAL LEARNING: Asking the right questions (CAM-JB-06-01)	
S$^+$	Asking the mechanical engineer where it was best to locate the HVAC system central plant that led to the elimination/need for a penthouse. (See CAM-NREL-06-04)
FUNCTIONAL/TECHNICAL SKILL: Daylight modeling (CAM-JB-06-02)	
S$^-$	Daylighting was not designed very well, at the time no access /familiarity with daylighting tools (computer simulation) existed on the team. The simplified LEED^{TM} 2% guideline was used and achieved, but it didn’t result in effective daylighting from an energy standpoint. Proper analyses were not run to inform the design decisions appropriately. The result is a lot of daylighting, but its impact on energy savings is disappointing.

<table>
<tr><td colspan="2">RISK ASSESSMENT:
Heat pumps & raised floor combination (CAM-JB-06-03)</td></tr>
<tr><td>S^+</td><td>This building is the first time that an underground source heat pumps and an underfloor air plenum distribution system was used. These attributes impacted how the design team developed the design in a major way. As a team, the potential benefits of the combination of the two were investigated (heightened energy performance) as well as the anticipated impact of the combination. The support of the owner representative in pursuing a new system combination once the potential benefits were identified helped move the decision along.</td></tr>
<tr><td colspan="2">TEAM INTEGRATION & LISTENING:
Developer sustainable experience (CAM-JT-06-01)</td></tr>
<tr><td>S^+</td><td>The developer had little to no green building experience prior to the project, but he was willing to listen and work with the team on those sustainable issues important to the team because he knew that they were a part of the goals the team was working for. This lack of knowledge was far outweighed by his willingness to integrate into the team.</td></tr>
<tr><td colspan="2">FUNCTIONAL/TECHNICAL SKILL, INFORMING OTHERS & LISTENING:
Photovoltaic design (CAM-JT-06-02)</td></tr>
<tr><td>S^+</td><td>Photovoltaics wouldn’t have ever been included in the building design if the energy, modeler/engineer hadn’t effectively shared information with the team and the team committed to move forward with it. Information was shared, the architect, engineers and owners listened and decided what would or wouldn’t be done in terms of energy design.</td></tr>
<tr><td colspan="2">SELF KNOWLEDGE & BUSINESS ACUMEN:
Developer experience with owner (CAM-JT-06-03)</td></tr>
<tr><td>S^+</td><td>The developer was already a successful provider of buildings to the commonwealth but didn’t have green experience and was willing to work towards sustainability. The architect worked with the commonwealth on the first green building in the state.</td></tr>
<tr><td colspan="2">FUNCTIONAL/TECHNICAL SKILL:
Building management systems design (CAM-JT-06-04)</td></tr>
<tr><td>S^+</td><td>The mechanical designer had a lot of experience with things that were important to the commonwealth, like the building management system. It was determined that a robust simple system. He was very helpful to recommend not going for some pretty pricy building energy management systems. He was able to say authoritatively that better than 80% of the energy management systems were either disabled or turned off in the first few months of building occupancy because the people operating the systems weren’t trained, changed or they encountered operational problems (I’m too hot/cold) that led to doing whatever needed to happen from an operations standpoint to make it comfortable.</td></tr>
</table>

INNOVATION MANAGEMENT, PROBLEM SOLVING, QUALITY DECISION MAKING & CREATIVITY: Risk assessment and taker (CAM-JT-06-05)	
S^+	We were the first to put together the heat pump and raised floor in a building. We made the decision in a couple of days because we had people that were willing to take risk in charge of the design. We gathered the information we were able to gather in the time frame available to us and made a decision to go with it and committed to that decision.
INNOVATION MANAGEMENT & TEAM INTEGRATION: Active owner participation (CAM-JM-06-01)	
S^+	The project went very well through the design phase, and it was the involvement of the owner that kept it on track and focused. I haven’t ever been on a project that had an owner that involved. The owner challenged the design team from an intent stand-point, not necessarily from a technical standpoint. Particularly the sizing issues stand out. Typically when you do a building like this from an air-conditioning standpoint you want to make sure you have more than enough capacity. You throw every safety factor that you can onto every calculation and you end up with somewhere between 350-400sf/ton. That is pretty standard in classic design schemes, but the desire to minimize energy use and loads led to an understanding of the how the building was being used. The owner emphasized the idea that this was a building for field engineers that 4 out of 5 days of the week were going to be in the field. Because of this, liberties in occupancy loads were able be taken that normally wouldn’t have been.
TEAM INTEGRATION, MOTIVATING OTHERS, INFORMING OTHERS & LISTENING: Architect as team champion (CAM-JM-06-02)	
S^+	The architect’s role as the champion was highly motivated to move this thing along in an integrated fashion. An example is The mechanical engineer hadn’t worked with any other architect that took the time and effort to get involved on the mechanical issues. There was a struggle with where to put the mechanical equipment, traditionally an architect designs the building and the mechanical engineer is asked to fit the equipment into the room. It was determined that that approach wasn’t going to work (and still achieve desired energy savings at conventional costs) so the architect asked me where I wanted the mechanical room and I picked some prime real-estate in the building (first floor core). This is ultimately where the room was located in the final design.

INFORMING OTHERS, FUNCTINOAL/TECHNICAL SKILL & INNOVATION MANAGEMENT: **Effective communicator (CAM-JM-06-03)**	
S^+	The owner, who understood the usage of the building, was able to convey that information to the design team with a certainty that the enabled the team to push the limits of traditional design. The building ended up near 650sf/ton, which is considerably less capacity than a building of this type would normally have. The main benefits were a significant reduction in the size of the entire mechanical system, including the loop field for the ground source heat pump. It paid off in reducing first cost and probably pays off in performance in the long run as well; the owner was able to ask the right questions regardless of his technical knowledge, and had a vision of what he wanted to do and forgo the conventional industry thinking for what made sense.
INTERPERSONAL SAVVY & PERSONAL LEARNING: **Asking the right questions (CAM-JM-06-04)**	
S^+	The owner was able to ask the right questions regardless of his technical knowledge. An example is the lead he took (through questions directed to the design team member’s possessing the appropriate technical knowledge) regarding the ground source heat pump and raised floor. This project is the first in the United States to utilize both technologies in conjunction.
FUNCTIONAL/TECHNICAL SKILL: **Energy equipment options (CAM-JM-06-07)**	
S^+	The mechanical engineer provided a good understanding of the various choices we had in terms of energy equipment (ground source heat pumps). He had spent his whole life working with heat pumps; as far as equipment the architect and owner wanted to understand the impact of the size and placement of equipment in order to make sure it was serviceable. They were concerned with more practical and less technical considerations such as operations and maintenance.
TEAM INTEGRATION & BUSINESS ACUMEN: **Underfloor air distribution (CAM-JM-06-09)**	
S^+	The developer and mechanical contractor had very little experience with sustainable buildings, the impact was not noticeable from my vantage point, to me it was all about attitude and not experience, the team was all willing to go down the sustainable road. The mechanical contractor, a tin knocker by trade, was involved in meetings where concepts (underfloor air distribution) were discussed that were a direct threat to his business but he still embraced the concepts for the betterment of the team.

INTERPERSONAL SAVVY, TEAM INTEGRATION & PROCESS MANAGEMENT: **Drawing documentation (CAM-JM-06-10)**	
S^+	The interaction between the mechanical engineering CAD operator and architect's draftsmen resulted in a process of working through all of the little details and avoiding conflicts in the construction documents. A lot of communication is required to develop CD's, the electronic world facilitates that communication because one designer can send a lot of documents back and forth many times in a day to another designer. Communication and interaction is really the critical element of any design process. No team member can be reluctant to pick up the phone or email to get the information that is needed. Direct communication is necessary, on this project there were clear lines of communication in all directions during the documentation phase as well as the entire project.
TECHNICAL/FUNCTIONAL SKILLS: **AutoCAD (CAM-JM-06-11)**	
S^+	Competencies possessed during construction document development included technical knowledge in the field of autoCAD (or computers depending on the technology being used) and interpersonal skills, you cannot be reluctant to pick up the phone or email to get the information that you need. Our mechanical draftsmen and architectural draftsmen had a clear unimpeded line of communication during documentation.
INTERPERSONAL SAVVY & FUNCTIONAL/TECHNICAL SKILLS: **Energy systems design (CAM-MS-06-01)**	
S^+	In general on high performance projects you need somebody that understands all the building energy systems that is not usually one person. It's a variety of skills from a variety of people including an architect, mechanical engineer, energy professional, and electrical engineer or lighting designer to look at it in detail. Interpersonal skills help. On this project the architect possessed general technical skills with regard to the energy systems and the energy consultant and mechanical engineer possessed the specific mechanical system knowledge required to appropriately integrate the building energy systems.
FUNCTIONAL/TECHNICAL SKILL **Envelope system selection (AIHI-DR-06-01)**	
S^+	Material vendor participation in the design of the windows added value through appropriate elimination of argon filled windows and use of triple-glazed low-e windows. This change was made possible by the sales representative's technical knowledge of the windows under consideration and effective communication skills exhibited when sharing pro's and con's of each window type

<table>
<tr><td colspan="2">FUNCTIONAL/TECHNICAL SKILLS & BUILDING EFFECTIVE TEAMS:
AutoCAD documentation by SIPS contractor (AIHI-DR-06-02)</td></tr>
<tr><td>S^+</td><td>AutoCAD design documents were issued to the SIPS contractor who had extensive 3-dimensional capabilities for shop drawing production during the documentation phase. The resultant product led to drawings that were more detailed and accurate than the auto CAD design documents leading to dimensional information that was able to inform other systems within the building design.</td></tr>
<tr><td colspan="2">BUILDING EFFECTIVE TEAMS, INFORMING OTHERS & TEAM INTEGRATION:
Misinterpretation of responsibilities (AIHI-DR-06-03)</td></tr>
<tr><td>S^-</td><td>Missing team competencies included poor interdisciplinary information processing skills, effective process planning and process management skills, and clear goal setting. These missing competencies directly resulted in misinterpretation of responsibilities (architects performing rework on window/SIPS panel design), unproductive meetings, and mixed messages from the core design team to student volunteers throughout the design process.</td></tr>
<tr><td colspan="2">INFORMING OTHERS, LISTENING, PROCESS MANAGEMENT & TEAM INTEGRATION:
Definition phase communication (AIHI-DR-06-04)</td></tr>
<tr><td>S^-</td><td>An initial building design plan was set forth with deadlines highlighted for major milestones. However, poor team and communication skills led to the dismissal of the conceptual designer after completion of the definition phase of the project was delayed.</td></tr>
<tr><td colspan="2">INFORMING OTHERS & PROCESS MANAGEMENT:
Project management (AIHI-AF-06-01)</td></tr>
<tr><td>S^-</td><td>The technical knowledge required to perform the necessary planning (i.e. schedules, design coordination, schedule implementation) were negligible or non-existent on the team.</td></tr>
<tr><td colspan="2">TIMELY DECISION MAKING & PERSONAL LEARNING:
Design manager experience (AIHI-AF-06-02)</td></tr>
<tr><td>S^+</td><td>The experience gained by working on the reservation on prior projects was a valuable asset brought to the team through the design manager. It allowed for decisions to be made in a timely manner on the behalf of the owner without needing to ask the questions and await a response.</td></tr>
<tr><td colspan="2">TIMELY DECISION MAKING & PROCESS MANAGEMENT:
Planning management implementation (AIHI-AF-06-03)</td></tr>
<tr><td>S^-</td><td>It was not clear who had the responsibility of keeping the project on schedule. This coupled with the fact that there was no timeline/schedule developed and shared at the beginning of the project resulted in mistimed decisions. An example is the location of ductwork design being completed</td></tr>
</table>

	prior truss design completion resulting in conflicts and redesign.
FUNCTIONAL/TECHNICAL SKILL: Local construction/design knowledge (AIHI-RX-06-01)	
S^+	The original control system that was selected had the closest operations support over 600-700 miles away. The fact that the controls contractor services the entire state of Montana and the neighboring states enabled them to know the controls maintenance operators in the area. The lack of knowledge of nearby service resulted in the selection of a digital operations system. The system can be maintained by individuals in the immediate proximity of the project.
INFORMING OTHERS: Controls design coordination (AIHI-RX-06-02)	
S^+	Communication from the controls contractor vantage point was good. The project manager explained the project expectations to the controls contractor. Then the mechanical engineer shared the appropriate information with the controls designer. At no point was I in need of information that I didn't have or was unable to get.
WRITTEN COMMUNICATION & UNDERSTANDING OTHERS: Mechanical and controls design coordination (AIHI-RX-06-03)	
S^-	A desired attribute of the mechanical engineer from the perspective of the controls contractor is the ability to articulate his/her thoughts and put them on paper. We are interpreting from 2-dimensional paper what the engineer wants to have done. A good set of documents and sequence fills in the blanks. If a set of documents that accurately represents the desired design exists, it is simple for us to design the detailed components of the system and plug information into the computer operating system. On this project that information wasn't always readily available in a timely manner. However, the working relationship between the mechanical engineer and controls contractor went a long way in avoiding potential issues that might arise out of this issue.
TEAM INTEGRATION: Volunteer work force management experience (AIHI-RX-06-04)	
S^+	The project manager has a lot of experience dealing with volunteers. This is important on the project because a large portion will be constructed by volunteers.
FUNCTIONAL/TECHNICAL SKILLS & SELF KNOWLEDGE: Material experience - SIPS (AIHI-SW-06-01)	
S^+	We utilized previous construction techniques we had used. SIPS panels were used the 2 prior years. Detailing and components were a little different but we were comfortable, same with engineered trusses, box beams, straw bales. By incorporating these into the design the on-site installation as well as design coordination was improved.

<table>
<tr><th colspan="2">INFORMING OTHERS, TEAM INTEGRATION & UNDERSTANDING OTHERS:
Building concept development (AIHI-SW-06-02)</th></tr>
<tr><td>S^-</td><td>An initial building footprint was developed by the entire team and the conceptual architect took that design and ran with it. They went off to do the design of it and to some members of our team did not communicate fully what they were doing for the design. The first time it was open for discussion was when they were done with the schematic design. That was not ideal. It was a reality that we were 3,000 miles away and our schedules did not coincide (summer). The footprint of the building was determined at the end of the timeframe which the concept architect had allotted for the project. There were serious questions as to whether or not it fit into the University’s stated mission and goals and safety of children. You have a group done with their work and the remaining team ended up changing that design to meet the goals and mission of the owner during the fall but also lost the engagement and interest of the concept architect. Hard feelings developed over this. That is not ideal in terms of a partnership. It allowed us to concentrate decision makers in one geographic location at PSU. It gets more complex than that as you move from site issues into building systems issues. There were people that had not worked with straw before, and details that introduced the need for higher levels of tolerances than could be built with the SIPS panels and cladding systems. Custom parts where there was highly specific SIPS panels that needed to be cut.</td></tr>
<tr><th colspan="2">TEAM INTEGRATION:
Individual goals (AIHI-SW-06-03)</th></tr>
<tr><td>S^-</td><td>Centralized decision making would be easy, but the team is so large managing everyone’s individual desires and tensions and research on a project makes it interesting. A lot of the problems we made ourselves, because each of us is interested in doing things that are not the best interest for the entire project from a research standpoint. Examples of individual interests include building with straw bale, we don’t have to, but that wouldn’t meet one of the major research interests, and building complexity, we could make a building that is simple in form, but that also wouldn’t meet a set of research goals.</td></tr>
</table>

<table>
<tr><td colspan="2">SELF KNOWLEDGE, CREATIVITY & INNOVATION MANAGEMENT:
Daycare project experience (AIHI-SW-06-04)</td></tr>
<tr><td>S^+</td><td>In the fall, after the concept architect concluded its piece, the project architect drew a schematic redesign essentially changing positions of things. Dimensionable drawings that ended up how it was primarily designed. At that point it was very rationale. 8’-0” OC center spacing, things that were repeatable. It is easier to draw and build this way. A new faculty member joined us that were interested in working on the project who had worked on a day care center before. He added the fin that gave a much more interesting profile and it improved daylighting intake and create a stack effect for natural ventilation. He also looked at SIPS panels in a new rhythm and designed windows that floated in the wall more providing interior lighting aimed to please the child occupants.</td></tr>
<tr><td colspan="2">INFORMING OTHERS, FUNCTIONAL/TECHNICAL SKILL & WRITTEN COMMUNICATION:
Foundation systems design coordination (AIHI-SW-06-05)</td></tr>
<tr><td>S^-</td><td>Facilitation of communication was not apparent during the design process. There is information the project architect would receive in a meeting that he hadn’t heard earlier. The foundation system is something that was talked about and discussed without the design architect’s input. It was one thing and changed to ICF’s and it wasn’t coordinated with SIPS panels. The SIPS panels couldn’t sit on ICF’s. The OSB of a SIPS panel has to sit on something hard to support the skin. The day of the pour the design architect asked if anyone had confirmed this (it hadn’t been coordinated), and the detail had to be changed on the spot. That is a fault of the design that resulted in field waste. What would have helped is if the team would have documented there ideas and shared them. It wasn’t until the wall section was drawn (1 week before the pour) that the potential issue was identified. It was assumed that the coordination of the two systems didn’t matter, so why waste time thinking about it. It’s not a big issue just something that would have saved everyone a lot of time and effort if the detail had been coordinated and documented. That is an example of negative interdisciplinary information sharing. Once you get it on paper it helps to facilitate the appropriate information sharing.</td></tr>
<tr><td colspan="2">INFORMING OTHERS:
Daylighting and energy models as informants to decisions (SALA-AT-06-01)</td></tr>
<tr><td>S^+</td><td>The exchange of information between the architects and engineers during the definition phase of the project was never a problem. The architects provided timely and accurate information when it was requested. The best example of this was the development of the building daylighting and energy models (see event SALA-AT-05-01).</td></tr>
</table>

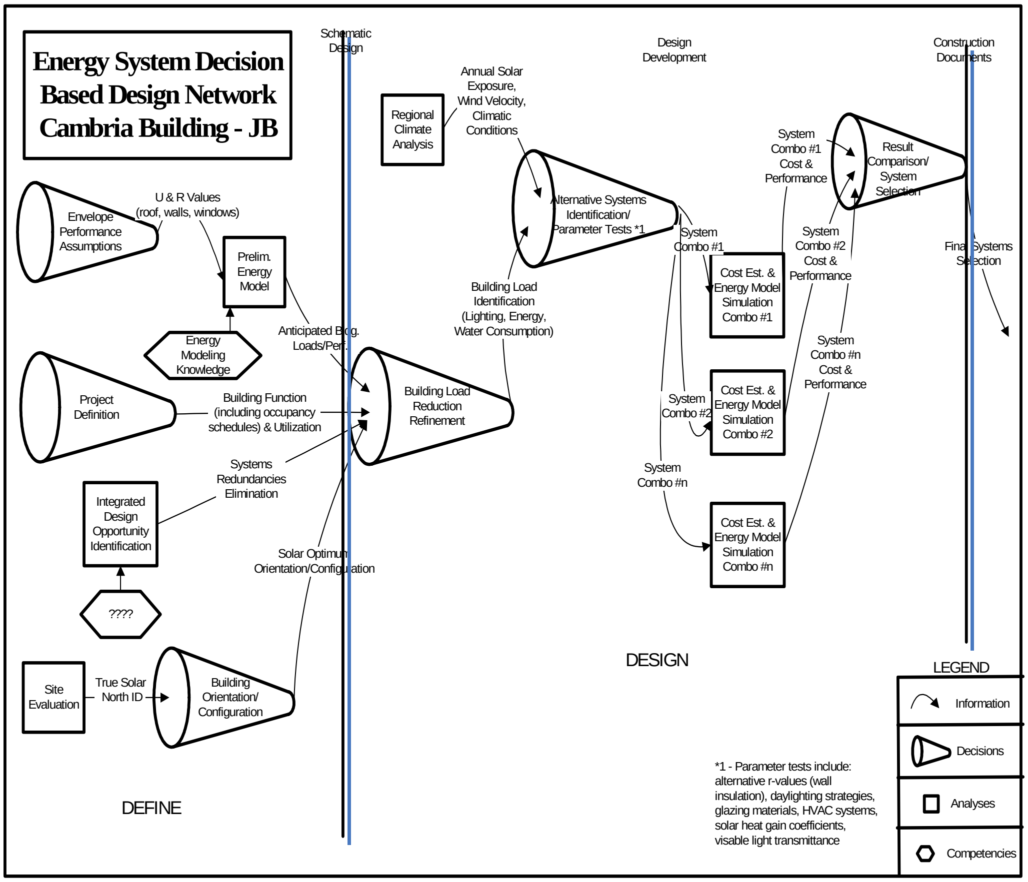
<table>
<tr><th colspan="2">QUALITY/TIMELY DECISION MAKING & FUNCTIONAL/TECHNICAL SKILL:
Operable window design (SALA-AT-06-02)</th></tr>
<tr><td>S^-</td><td>What you don’t want to do is say at an early stage you are going to achieve a shading coefficient of 1 and have only one window or shutter provider that goes out of business when it is to be purchased. An individual with knowledge of available materials and the associated characteristics so that an achievable design scheme is developed is imperative in integrated designs, because so many systems depend on others. Mechanically operable windows in the building were almost eliminated during a value engineering process after initial bids were received. Targeting this system was caused by many factors, one of which was the fact that it was an apparent ‘proprietary’ item.</td></tr>
<tr><th colspan="2">WRITTEN COMMUNICATIONS & BUILDING EFFECTIVE TEAMS:
Conceptual phase designer integration (SALA-AT-06-03)</th></tr>
<tr><td>S^-</td><td>The building design team experienced high levels of designer turn over. These were influenced mainly in the way the owner selected and contracted designers (with different definition and design/documentation phase landscape designers, mechanical engineers, electrical engineers, structural engineers and architects). This increased the importance of effective documentation skills as a core team competency. In the case of the heat recovery system, no documentation of what considerations were modeled or evaluated was created early in the definition phase of the project. When the issue arose later in the definition and documentation phases, this lack of documentation contributed to re-work that ensued in an effort to evaluate the alternative system.</td></tr>
<tr><th colspan="2">FUNCTIONAL/TECHNICAL SKILL:
Design phase constructability knowledge (SALA-AT-06-04)</th></tr>
<tr><td>S^+</td><td>The project manager/project architect possessed a great deal of experience in the design process not only early in the design, but also through construction. This knowledge facilitated decisions early in the design that considered constructability issues.</td></tr>
<tr><th colspan="2">PRIORITY SETTING & TEAM INTEGRATION:
Energy efficient design (SALA-JS-06-01)</th></tr>
<tr><td>S^+</td><td>There was a group effort on the design team’s part to make sure that the building was energy efficient and the systems included were efficient.</td></tr>
</table>

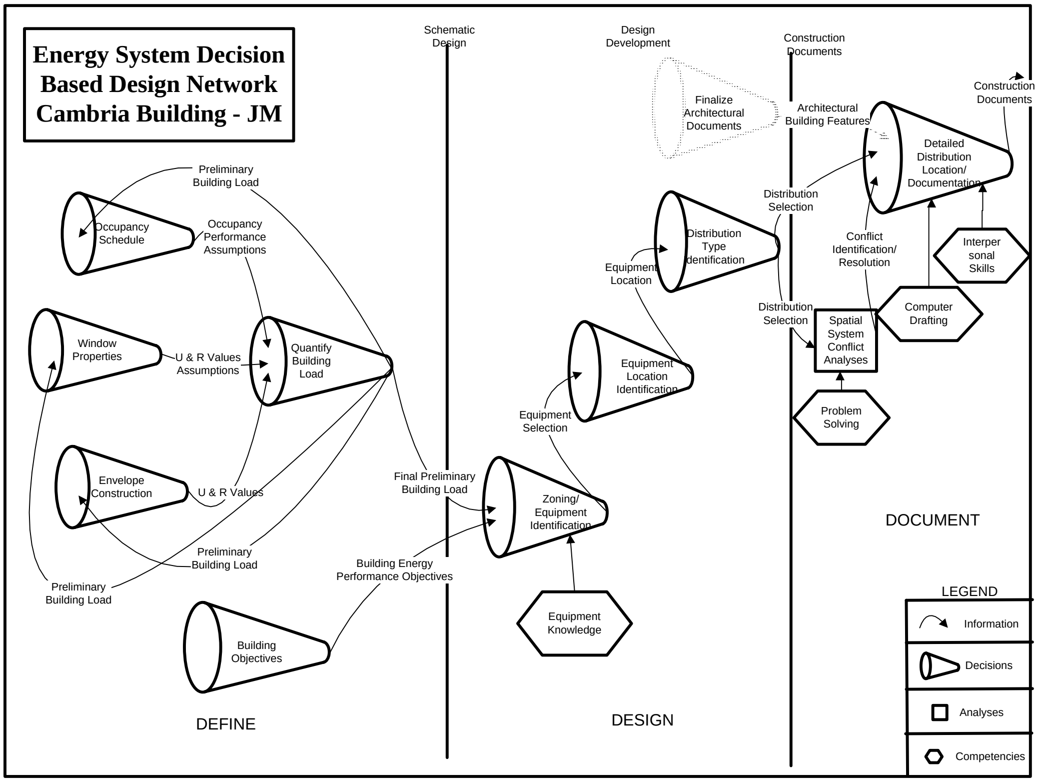
<table>
<tr><td colspan="2">FUNCTIONAL/TECHNICAL SKILL:
Modeling expertise (SALA-JS-06-02)</td></tr>
<tr><td>S$^+$</td><td>If we (mechanical engineering firm with limited high performance design experience) had done the design from the beginning to end, we wouldn’t have had the benefit of concept mechanical engineer’s experience in the daylighting models. This is something we could do very easily in house (but didn’t at the time of the project). In addition, at the time we didn’t have a lot of experience in the energy models.</td></tr>
<tr><td colspan="2">INFORMING OTHERS & TIMELY DECISION MAKING:
Owner, architect, engineer information quality (SALA-JS-06-04)</td></tr>
<tr><td>S$^-$</td><td>The information transfer on the project was good on the design team; we had trouble getting information from the owner. The owner was slow to respond to questions and provide timely information (see event SALA-JS-03-04).</td></tr>
<tr><td colspan="2">FUNCTIONAL/TECHNICAL SKILL:
Sustainable expertise (SALA-JN-06-01)</td></tr>
<tr><td>S$^+$</td><td>The concept architect and mechanical engineer are both internationally known firms in the field of sustainable design. Each has designed multiple buildings that required the optimization of envelope and building systems.</td></tr>
<tr><td colspan="2">PRIORITY SETTING, MOTIVATING OTHERS & INNOVATION MANAGEMENT:
LEED^{TM} measurement system (SALA-JN-06-02)</td></tr>
<tr><td>S$^+$</td><td>The architectural and engineering design firms were committed to developing an innovative design that met the goals of the University. The University supported the goal to produce a sustainable building utilizing all means necessary. This is apparent in the acceptance and incorporation of LEED^{TM} as a metrics to measure and facilitate the building’s sustainable attributes.</td></tr>
<tr><td colspan="2">BUILDING EFFECTIVE TEAMS:
Team size (SALA-RR-06-01)</td></tr>
<tr><td>S$^+$</td><td>Great pains were taken to keep the team to a limited number of people (especially in the user group category). It was the belief of the owner that the group was small enough in number to convene and communicate easily, to have open, interactive discussion and to understand the members’ roles and responsibilities.</td></tr>
<tr><td colspan="2">BUILDING EFFECTIVE TEAMS:
Team member responsibilities identifications (SALA-RR-06-02)</td></tr>
<tr><td>S$^-$</td><td>Never outlined what each team member was responsible for, this led to different direction from multiple PSU members ultimately sending a confusing message to the designers.</td></tr>
</table>

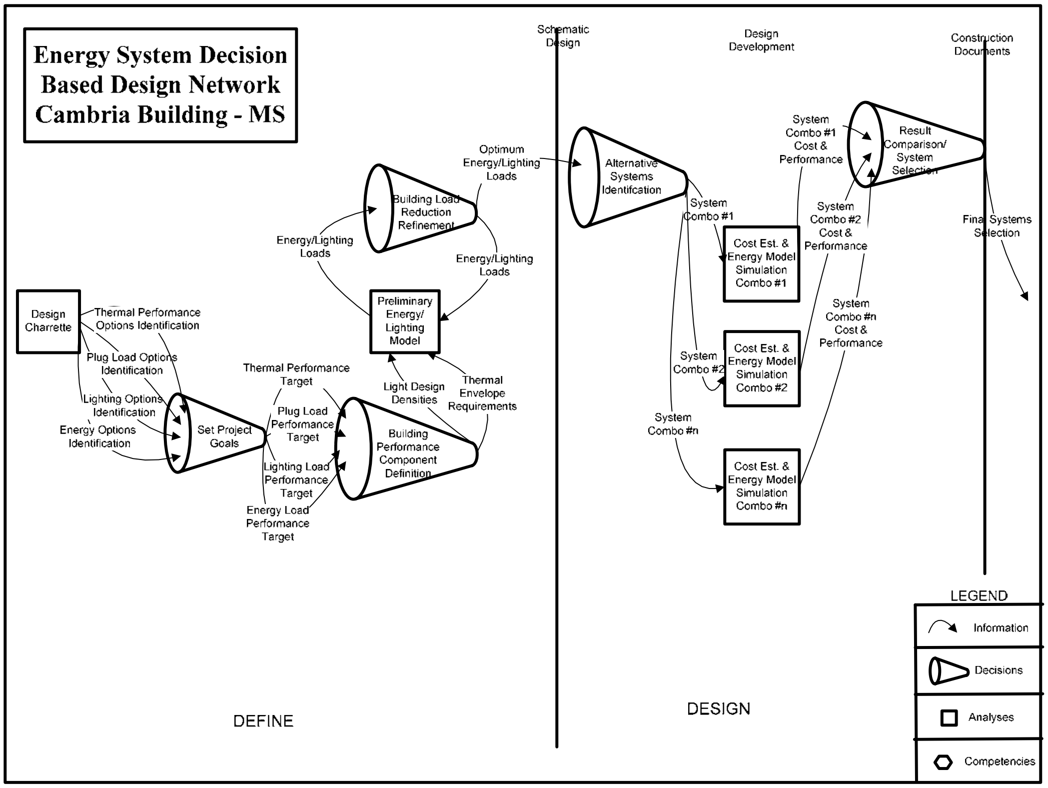
<table>
<tr><td colspan="2">BUSINESS ACUMEN:
Mechanical engineer accountability (SALA-RR-06-03)</td></tr>
<tr><td>S^-</td><td>The concept architect and mechanical engineer held themselves accountable for individually and jointly as measured against specific goals (LEED^{TM}), however the mechanical engineer of record, did not do the same. This became apparent during value engineering sessions in the bidding phase of the project (see event SALA-AT-06-02)</td></tr>
<tr><td colspan="2">FUNCTIONAL/TECHNICAL SKILL & TEAM INTEGRATION:
Energy system expertise (SALA-RR-06-04)</td></tr>
<tr><td>S^+</td><td>The mechanical engineer was responsible for developing multiple options for the building concept including shape, orientation and overall mass at the design charette. Their input combined with the input of the landscape architect led to the final building design concept.</td></tr>
<tr><td colspan="2">FUNCTIONAL/TECHNICAL SKILL:
Computer modeling (SALA-RR-06-05)</td></tr>
<tr><td>S^+</td><td>Energy and light studies in the form of interactive models were utilized to inform design decisions and develop the exterior treatments and space uses.</td></tr>
<tr><td colspan="2">FUNCTIONAL/TECHNICAL SKILL:
Sustainable expertise (SALA-RR-06-06)</td></tr>
<tr><td>S^+</td><td>The conceptual phase architect and mechanical engineer were both selected large in part because of their sustainable experience. Both firms are leaders in energy efficient and sustainable design, with multiple projects completed at the time of selection.</td></tr>
</table>

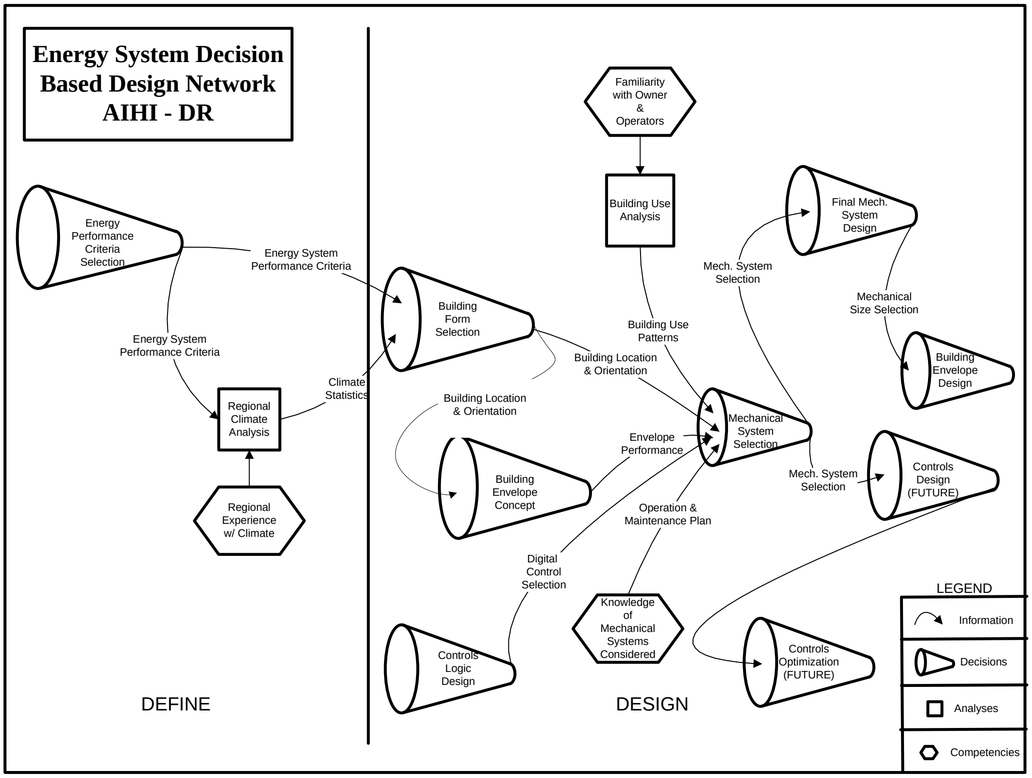
Appendix I

Case Study Process Models

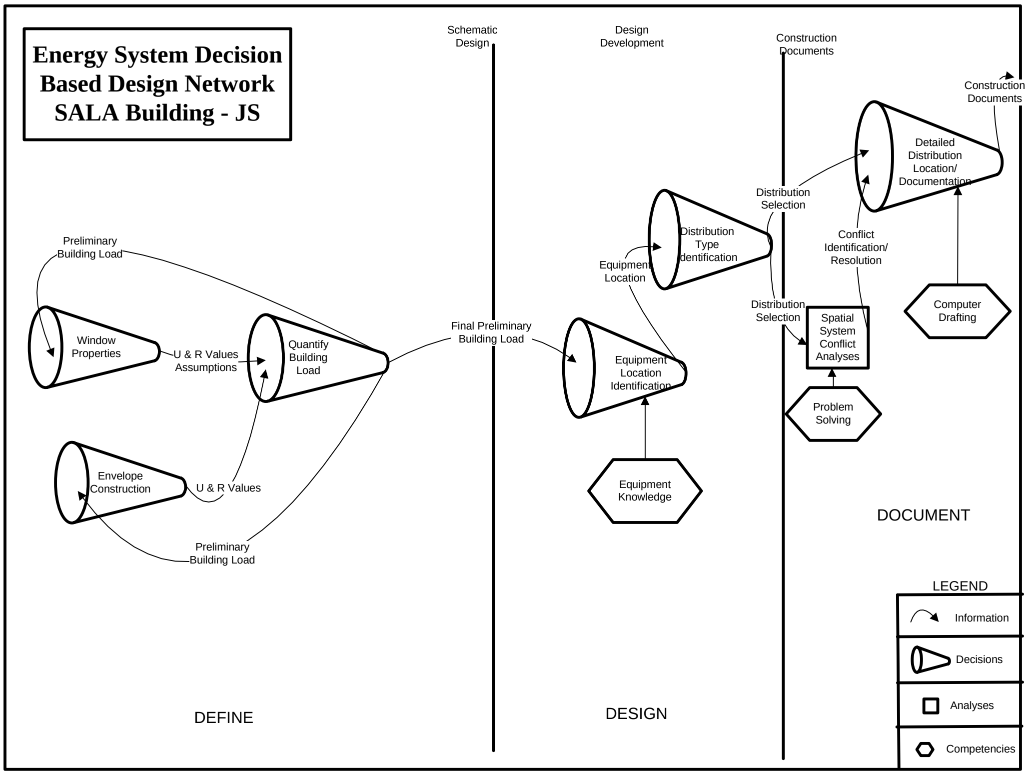



Energy System Decision Based Design Network Cambria Building - JM
Schematic Design
Design Development
Construction Documents
Construction Documents
Finalize Architectural Documents
Architectural Building Features
Detailed Distribution Location/ Documentation
Distribution Selection
Conflict Identification/ Resolution
Interper sonal Skills
Equipment Location
Distribution Type Identification
Distribution Selection
Spatial System Conflict Analyses
Computer Drafting
Problem Solving
Equipment Location Identification
Equipment Selection
Preliminary Building Load
Occupancy Schedule
Occupancy Performance Assumptions
Window Properties
U & R Values Assumptions
Quantify Building Load
Envelope Construction
U & R Values
Final Preliminary Building Load
Zoning/ Equipment Identification
Preliminary Building Load
Preliminary Building Load
Building Energy Performance Objectives
Equipment Knowledge
Building Objectives
DOCUMENT
DEFINE
DESIGN
LEGEND
Information
Decisions
Analyses
Competencies


Energy System Decision Based Design Network Cambria Building - MS
Schematic Design
Design Development
Construction Documents
Optimum Energy/Lighting Loads
Alternative Systems Identifcation
System Combo #1 Cost & Performance
Result Comparison/ System Selection
Building Load Reduction Refinement
Energy/Lighting Loads
Energy/Lighting Loads
System Combo #1
System Combo #2 Cost & Performance
Final Systems Selection
Cost Est. & Energy Model Simulation Combo #1
Design Charrette
Thermal Performance Options Identification
Preliminary Energy/ Lighting Model
System Combo #n Cost & Performance
Plug Load Options Identification
Thermal Performance Target
Light Design Densities
Thermal Envelope Requirements
System Combo #2
Cost Est. & Energy Model Simulation Combo #2
Lighting Options Identification
Energy Options Identification
Set Project Goals
Plug Load Performance Target
Building Performance Component Definition
System Combo #n
Lighting Load Performance Target
Energy Load Performance Target
Cost Est. & Energy Model Simulation Combo #n
LEGEND
Information
Decisions
Analyses
Competencies
DEFINE
DESIGN



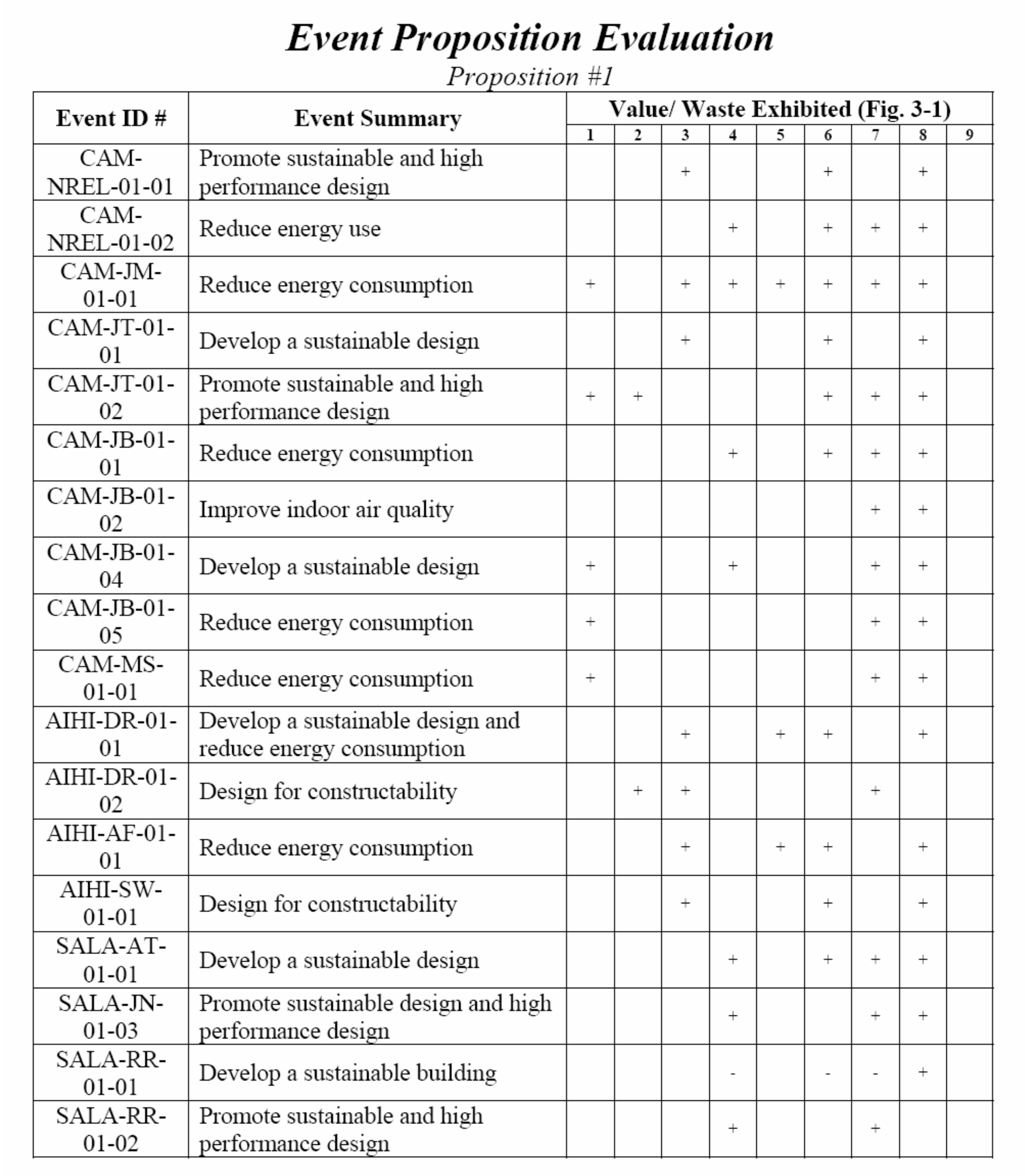
Energy System Decision Based Design Network AIHI - DR



Energy System Decision Based Design Network SALA Building - JS

Appendix J

Proposition Value Tables



Event Proposition Evaluation

Proposition #1

Event ID #	Event Summary	Value/ Waste Exhibited (Fig. 3-1)								
		1	2	3	4	5	6	7	8	9
CAM-NREL-01-01	Promote sustainable and high performance design			+			+		+	
CAM-NREL-01-02	Reduce energy use				+		+	+	+	
CAM-JM-01-01	Reduce energy consumption	+		+	+	+	+	+	+	
CAM-JT-01-01	Develop a sustainable design			+			+		+	
CAM-JT-01-02	Promote sustainable and high performance design	+	+				+	+	+	
CAM-JB-01-01	Reduce energy consumption				+		+	+	+	
CAM-JB-01-02	Improve indoor air quality							+	+	
CAM-JB-01-04	Develop a sustainable design	+			+			+	+	
CAM-JB-01-05	Reduce energy consumption	+						+	+	
CAM-MS-01-01	Reduce energy consumption	+						+	+	
AIHI-DR-01-01	Develop a sustainable design and reduce energy consumption			+		+	+		+	
AIHI-DR-01-02	Design for constructability		+	+				+		
AIHI-AF-01-01	Reduce energy consumption			+		+	+		+	
AIHI-SW-01-01	Design for constructability			+			+		+	
SALA-AT-01-01	Develop a sustainable design				+		+	+	+	
SALA-JN-01-03	Promote sustainable design and high performance design				+			+	+	
SALA-RR-01-01	Develop a sustainable building				-		-	-	+	
SALA-RR-01-02	Promote sustainable and high performance design				+			+		

Event Proposition Evaluation

Proposition #3

Event ID #	Event Summary	Value/ Waste Exhibited (Fig. 3-1)								
		1	2	3	4	5	6	7	8	9
CAM-NREL-03-01	Design concept changes	-		+		-	-	+	+	+
CAM-NREL-03-02	Daylighting and acoustical performance	+	+						+	
CAM-NREL-03-03	Building fenestration considerations	+						+	+	
CAM-NREL-03-04	Daylighting and lighting design	-	-	-		-	-	+		
CAM-NREL-03-05	Exterior lighting design	-	-	-		-	-	+		
CAM-NREL-03-06	Heating, ventilation, air conditioning systems	+			+			+	+	
CAM-NREL-03-07	Mechanical room location selection	+	+		+	+	+	+	+	
CAM-NREL-03-10	Energy efficient design changes			+					+	
CAM-JM-03-01	Elimination of penthouse mechanical room	+	+		+	+	+	+	+	
CAM-JT-03-01	Mechanical room relocation	+	+		+	+	+	+	+	
CAM-JB-03-01	Building configuration (offices)			+					+	
CAM-JB-03-02	Load reduction			+		+		+	+	
CAM-JB-03-03	Parameter tests			+	+			+	+	
CAM-JB-03-04	Building mechanical room relocation	+			+				+	
CAM-JB-03-05	Building orientation								+	
AIHI-DR-03-01	Building footprint decision timing		-	-		-	-			
AIHI-DR-03-02	Definition phase design communication		-	-		-	-	-		
AIHI-DR-03-03	Incomplete design documentation		-	-		-	-	-		
AIHI-DR-03-04	Energy system decision timing		-	-		-	-	-		
AIHI-DR-03-05	Control selection		-	-		-	-	-		
AIHI-R?-03-01	Final controls system selection		-	-		-	-	-		+

Event Proposition Evaluation

Proposition #3

AIHI-R?-03-02	Control wire routing	+	+					+		
AIHI-R?-03-03	Controls design	+	+					+		
AIHI-AF-03-01	Timely incorporation of energy system design recommendations	-	-							+
AIHI-AF-03-02	Untimely truss selection	-	-							+
AIHI-SW-03-01	Utility relocation design					-				
AIHI-SW-03-02	SIPS size selection					-				+
AIHI-SW-03-03	Timing of competency involvement					-				+
AIHI-SW-03-04	Design development documentation			-			-			
AIHI-SW-03-05	Foundation system design	-	-							+
AIHI-SW-03-06	System coordination			-		-		-		+
AIHI-SW-03-07	Conceptual design review					-				+
SALA-JN-03-01	Transition of MEP design responsibility	-	-	-		-				+
SALA-JN-03-02	Transition of landscape design responsibility	+	+	+		+				-
SALA-JN-03-03	Transition of structural design responsibility	-	-	-		-				+
SALA-JN-03-04	Initial structural load design guidelines	-	-	-		-				+
SALA-JN-03-05	Heating system design	-	-	-	-		-		-	+
SALA-JS-03-01	Mechanical system selection	-	-	-	-		-		-	+
SALA-JS-03-02	Energy recovery mechanical system design	-	-		-		-		-	+
SALA-JS-03-03	Air louver location	-	-				-			+
SALA-JS-03-04	Classroom committee design changes	-	-				-			+
SALA-JS-03-05	Notification of changes	-		-						+
SALA-JS-	Mechanical system space					+	+			

Event Proposition Evaluation

Proposition #3

03-06	coordination									
SALA-AT-03-01	Heating/cooling system consideration						-	-	-	
SALA-RR-03-01	Architect responsibility transition	-								+

Event Proposition Evaluation

Proposition #4

Event ID #	Event Summary	Value/ Waste Exhibited (Fig. 3-1)								
		1	2	3	4	5	6	7	8	9
CAM-NREL-05-01	Building system selection	+			+		+	+	+	
CAM-NREL-05-02	Building configuration/ orientation determination	+	+	+	+	+	+	+	+	
CAM-NREL-05-03	Building configuration/ orientation determination			+		+			+	+
CAM-JB-05-01	Building energy load determination/minimization	+		+				+	+	
CAM-JB-05-02	Building system selection	+			+			+	+	
CAM-JB-05-03	Building system selection			-						
CAM-JB-05-04	Integrated design solution selection				-			-	-	
CAM-JB-05-05	Building energy load determination/minimization			+		+		+	+	
CAM-JT-05-02	Building energy load determination/minimization	+			+		+	+	+	
CAM-MS-05-01	Integrated design solution selection				-			-	-	
CAM-JM-05-01	Building system selection				+			+	+	
AIHI-DR-05-01	Building system selection	-		-						
AIHI-DR-05-02	Building system selection			+				+	+	
AIHI-DR-05-03	Material selection							+	+	
AIHI-DR-05-04	Building system selection	-		-		-			-	
AIHI-DR-05-05	Building system selection		-	-		-		-	-	
AIHI-DR-05-06	Building configuration/ orientation determination					-		-		
AIHI-AF-05-01	Building systems selection	-					-	-		
AIHI-R?-05-01	Building systems selection							+		
AIHI-SW-05-01	Building systems selection	-		-						
AIHI-SW-05-02	Building systems selection	-		-						
AIHI-SW-05-03	Building systems selection			-	-	-				+
SALA-AT-05-01	Building configuration/ orientation determination							+	+	
SALA-AT-05-02	Building energy load determination/ minimization							+	+	
SALA-JS-05-01	Building systems selection					-		-	-	+

Event ID #	**Event Summary**	**Value/ Waste Exhibited (Fig. 3-1)**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
SALA-JN-05-01	Building systems selection					-		-	-	+
SALA-JN-05-02	Building systems selection				+			+	+	
SALA-JN-05-03	Building systems selection							+	+	
SALA-JN-05-04	Building systems selection					-	-	-	-	+
SALA-RR-05-01	Building configuration/ orientation determination				+		+		+	

Event Proposition Evaluation

Proposition #5

Event ID #	Event Summary	Value/Waste Exhibited (Fig. 3-1)								
		1	2	3	4	5	6	7	9	8
CAM-NREL-06-01	Functional/technical skill	+	+		+			+		
CAM-NREL-06-02	Timely decision making & dealing with ambiguity	-	-	-	-	-	-			+
CAM-NREL-06-03	Team integration & functional/ technical skill	+	+		+			+	+	
CAM-NREL-06-04	Problem solving, team integration & functional /technical skill	+	+		+			+	+	
CAM-NREL-06-05	Functional/technical skill & informing others	+		+	+		+	+	+	
CAM-JB-06-01	Problem solving, interpersonal savvy, listening & personal learning	+	+		+			+	+	
CAM-JB-06-02	Functional/technical skill	-	-		-			-	-	
CAM-JB-06-03	Risk assessment				+				+	
CAM-JT-06-01	Team integration & listening				+					
CAM-JT-06-02	Functional/technical skill, informing others & listening				+			+	+	
CAM-JT-06-03	Self knowledge & business acumen				+			+		
CAM-JT-06-04	Functional/technical skill				+			+	+	
CAM-JT-06-05	Innovation management, risk assessment, quality decision making & creativity				+			+	+	
CAM-JM-06-01	Innovation management & team integration	+		+	+	+		+		

Event ID #	**Event Summary**	**Value/Waste Exhibited (Fig. 3-1)**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**8**
CAM-JM-06-02	Team integration, motivating others, informing others & listening				+					
CAM-JM-06-03	Informing others, functional/technical skill & innovation management	+			+			+	+	
CAM-JM-06-04	Interpersonal savvy & personal learning				+				+	
CAM-JM-06-07	Functional/technical skill				+			+		
CAM-JM-06-09	Team integration & business acumen				+			+	+	
CAM-JM-06-10	Interpersonal savvy, team integration & process management				+			+		
CAM-JM-06-11	Technical/functional skills				+			+		
CAM-MS-06-01	Interpersonal savvy & functional/technical skills				+				+	
AIHI-DR-06-01	Functional/technical skill				+					
AIHI-DR-06-02	Functional/technical skills & building effective teams				-			-		
AIHI-DR-06-03	Building effective teams, team integration & informing others				-					
AIHI-DR-06-04	Informing others, listening, team integration & process management				-					
AIHI-AF-06-01	Process management & informing others				-					
AIHI-AF-06-02	Timely decision making & personal learning				+			+		
AIHI-AF-06-03	Timely decision making & process management				-			-		
AIHI-R?-06-01	Functional/technical learning				+			+		
AIHI-R?-06-02	Informing others				+			+		
AIHI-R?-06-03	Written communication & understanding others			-	-					
AIHI-R?-06-04	Team integration				+			+		
AIHI-SW-06-01	Functional/technical skills & self knowledge			+	+					
AIHI-SW-06-2	Informing others, team integration & understanding others			-	-		-	-		

Event ID #	Event Summary	Value/Waste Exhibited (Fig. 3-1)								
		1	2	3	4	5	6	7	9	8
AIHI-SW-06-03	Team integration			-	-		-	-		
AIHI-SW-06-04	Self knowledge, creativity & innovation management				+				+	
AIHI-SW-06-05	Informing others, functional/technical skills & written communication			-	-		-	-		
SALA-AT-06-01	Informing others	+		+	+			+		
SALA-AT-06-02	Quality/timely decision making & functional/technical skill				+				+	
SALA-AT-06-03	Written communications & building effective teams							-	-	
SALA-AT-06-04	Functional/technical skill			+	+					
SALA-JS-06-01	Priority setting & team integration				+			+		
SALA-JS-06-02	Functional/technical skill				+			+	+	
SALA-JS-06-04	Informing others & timely decision making	-		-	-	-	-			
SALA-JN-06-01	Functional/technical skill				+			+	+	
SALA-JN-06-02	Priority setting, motivating others & innovation management				+		+		+	
SALA-RR-06-01	Building effective teams			-	-		-	-		
SALA-RR-06-02	Building effective teams				-					
SALA-RR-06-03	Business acumen				-				-	
SALA-RR-06-04	Functional/technical skill & team integration				+			+	+	
SALA-RR-06-05	Functional/technical skill				+			+	+	
SALA-RR-06-06	Functional/technical skill				+				+	

VITA

Chris Magent graduated from The Pennsylvania State University in 1996 with a Bachelor of Architectural Engineering. Upon graduation, Chris worked for Clark Construction Company in Bethesda, MD on the Washington Redskin's football stadium. After completing his field assignment, Chris worked in the corporate estimating department for one year. In 1998, Chris joined Turner Construction Company and completed project management assignments on a $20 million law firm renovation project, a $40 million Performing Arts Theatre and classroom building for Carnegie Mellon University, and a $60 million Information Sciences and Technology Building for Penn State University. While working for Turner Construction, Chris attended graduate school at The University of Pittsburgh and received a Master of Science degree in Civil Engineering.

When attending graduate school at Penn State, Chris was an integral member of the Lean and Green Research Initiative. Contributions included co-author on a sustainability guide for field use, development of an education seminar for construction management firms on sustainability, chairman of the 2000-2004 seminar and roundtable events hosted by the Partnership for Achieving Construction Excellence (PACE) and event coordinator for the First Annual Integrated Roundtable Discussion held in Tarrytown, NY. While at Penn State, Chris was the instructor for an undergraduate pre-construction course and he served as a thesis advisor to several students.

Chris' interests include improving design processes and management through evaluation process model research and identifying techniques to improve the design process for buildings. He intends to pursue a career that will allow him to combine his interest and knowledge in design management with his experience in construction management.