HIGH PERFORMANCE BUILDING DESIGN
PROCESS MODEL

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ABSTRACT
High Performance “sustainable” or “green” buildings are emerging as an important market in the United States and around the world. The increased demand for high performance buildings has simultaneously created an opportunity to rethink the design process. To optimize the design process for high performance buildings, a project management environment that unites architects, engineers, and builders must be created and key design processes and competencies of design teams must be defined. This paper presents the initial results of an effort to model the process and discipline requirements for the design of high performance buildings. The Building Design Process Model for High Performance Buildings (BDPMHP) and the accompanying Cross-Functional Design Process Map for High Performance Buildings (CFDPMHP) are presented as mechanisms to assist in the transformation of traditional design processes. Background and design development models of the BDPMHP and CFDPMHP are presented and testing of the BDPMHP through case study analysis and virtual design team simulations is described. Emerging patterns and key processes on successful high-performance building projects are identified. This research benefits facility owners by identifying key attributes of a high performance design process that decrease design process waste and reduce the first-cost of high performance projects.

KEY WORDS

INTRODUCTION
The increased demand for sustainable or green buildings indicates the emergence of an important market in the United States. This demand has created an opportunity and the need to rethink the traditional design process for buildings. High performance buildings require close integration of building systems and more intense energy, daylighting, and material analysis during design. The effects of wasteful and poorly managed design processes are magnified on high performance projects, as they detract directly from efforts to fine tune the final design of the project. Design process waste also results in higher first costs and often inhibits decisions to pursue a high performance building. A need exists for a more defined model of the design process for high performance buildings.

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This paper presents models of the process and discipline requirements needed to efficiently design high performance buildings. These models help to articulate process and discipline requirements for the assessment, evaluation and continuous improvement of the design process for high performance buildings. Two parts of this model form the focus of this paper: 1.) The Building Design Process Model for High Performance Buildings (BDPM\textsuperscript{HP}); and 2.) the accompanying Cross-Functional Design Process Map for High Performance Buildings (CFDPM\textsuperscript{HP}).

The BDPM\textsuperscript{HP} provides a guide for key design process decisions and commitments for high performance buildings that have been identified on successful high performance projects based on principles of concurrent engineering and lean production theory. The CFDPM\textsuperscript{HP} highlights key cross-disciplinary collaborations and the proper timing for each, as well as core competency requirements for participants, which has been found to be highly undefined on case study projects.

Using the BDPM\textsuperscript{HP} and CFDPM\textsuperscript{HP} metrics as the principal framework for analysis of selected case studies, key attributes of a high performance design process are identified. Virtual design team simulation using Simvision\textsuperscript{©} helps demonstrate how waste (rework) can be reduced through the practices defined in the BDPM\textsuperscript{HP}. Early findings identify process patterns that exist on successful high-performance building projects. The key patterns identified include project-specific process design, alignment of team competencies, and clear commitments to defined design tolerances during the process. This research benefits facility owners and design teams by identifying key attributes of a high performance design process that can improve the building design process through reduced process waste resulting in lower first cost for high performance facilities.

BACKGROUND

"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.”

(USGBC 2003).

Representative definitions of sustainable and high performance buildings have many similarities. Both identify the importance of considering resource consumption and creating a healthy place to live and work. A key differentiator between the two, however, is the emphasis each places on the building’s operating resource consumption and the quality of the occupant environment (indoor air quality) relative to other more global environmental topics. Sustainable or green buildings place a broad emphasis on global ecological issues, while high performance buildings are characterized by energy efficiency and long term life cycle costs.

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 aims to reduce first-time and facility operating costs.”

TRADITIONAL DESIGN PROCESS

The American Council of Engineering Companies (ACEC) found that design information
for buildings has declined and become increasingly uncoordinated (ACEC 2003). Characterized as sequential and fragmented, traditional design processes are laden with process waste, duplication of efforts, and errors. While many designers and engineers profess to be “system” thinkers, the reality of specialization, isolated decision-making, conventional practice methods, and the speed of the building process conspire to prevent achievable optimizations of most every system engaged when buildings are produced (REED 2000). These sources of waste and mistimed collaboration are amplified and have greater consequences in the design of high performance buildings, where system integration and collaboration during design are paramount. Defining the design process for high performance buildings will provide a mechanism to aid in true “system” thinking during the design process.

Construction engineering and architectural professions are attempting to narrow the gap between the disciplines (Rittelmann, 2000). As a result, the identification of core competencies possessed by disciplines can become 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).

**LEAN THEORY AND CONCURRENT ENGINEERING**

Lean production emphasizes the elimination of waste in the process to improve the performance of production systems. To improve the opportunity for waste reduction, Womack and Jones 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 (Womack and Jones, 1996). Lean management concepts provide a different philosophy for the process of building design than traditional design processes.

Initially proposed as a concept to reduce product development time by simultaneously addressing product design, development, manufacturing, and marketing processes, concurrent engineering requires engineering activities to be integrated and performed in a parallel (Prasad, 1996). Concurrent engineering principles are highly aligned with the integrated design process for sustainable buildings. A premium is placed by both on effective cross-disciplinary collaborations and appropriate involvement of design expertise. Lean principles, combined with established principals of concurrent engineering, provide “filters” for the identification of key activities in the BDPMHP. The specific evaluation filters that have been developed and utilized in this research are:

- **Deliver the project while maximizing value and minimizing waste**
- **Define, compare and optimize project specific design goals and objectives**
- **Place emphasis on both value added processes, and the minimization of lost value during the design process**
- **Involve advice of downstream stakeholders in upstream decisions**
• Ensure all members of the project design team are aware of design activities and decisions
• The design must be made in a manner to facilitate effective information sharing
• Take into account constructability elements such as construction methods, technology, equipment, and construction sequencing
• Fully complete essential parts of design to enable construction commencement without 100% design decisions

HIGH PERFORMANCE BUILDING DESIGN PROCESS MODEL (BDPM<sup>HP</sup>)

The BDPM<sup>HP</sup> provides a design process model for high performance buildings that places emphasis on the energy optimization process in building design. The model provides a guide for key design process decisions and commitments for high performance building design, and provides added definition of the design process than traditional terms of conceptual, schematic, development, and construction drawing definitions of the process. Figure 1 illustrates key elements of the BDPM<sup>HP</sup> (shaded) in the context of the traditional design process. (Riley et al. 2003). Importantly, the shop drawing process is included in this model, in recognition of the role of specialty contractors in the completion of design processes.

Figure 1: Level I: Building Design Process Model for High-Performance Projects
(Adopted from Riley, Magent, Horman, 2003)
LEVEL II – ENERGY OPTIMIZATION PROCESS

The BDPM\textsuperscript{HP} adopts descriptive definitions for the phases of the design process as “define”, “design” and “document”. Within these major phases, energy efficiency is a major emphasis and thus the energy optimization process of the BDPM\textsuperscript{HP} and is the current area of emphasis in this research. The balance of building envelope performance attributes with those of the mechanical system is extremely critical in high performance buildings. A detailed analysis of the energy optimization process has been developed and is being evaluated through case studies. A conceptual level process map (Level II) of the BDPM\textsuperscript{HP} for the process of energy optimization is shown in Figure 2.

Define Phase

Traditionally labeled pre-planning, conceptual and schematic design phases are included in the define phase of the energy optimization process map. This terminology effectively articulates the goal of the phase and assists in focusing efforts in the proper direction. The design phase for energy optimization is closely aligned with the traditional design process, with team formation and information gathering completed at this time.

(0) Assemble High Performance Team: Assembling high performance teams is the first critical activity in the energy optimization design process. Critical team traits that require considerations when assembling the high performance team are presented later in the discussion of the CFDPM\textsuperscript{HP}. These traits aid in many facets of the design, enabling effective delivery of the key activities that make up the energy optimization process.

(1) Identify Basic Constraints, Footprint Options and Goals: 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.

Design Phase

Traditionally the schematic design and design development phases are 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 included in the design phase.

(2) **Design Optimization Simulation:** During the energy optimization design process, this activity focuses on initially identifying optimum building performance opportunities through basic computer simulations.

(3) **Evaluate & Integrate Basic relationships Between Systems:** Design optimization simulations should be considered when building system integration is performed. Special consideration given to the building envelope and HVAC system relationship in an effort to reduce overall energy consumption while minimizing costs.

(4) **Inform with Results:** Once initial systems are developed and their relationships identified, team members are to be informed of all system designs. The impacts of changing any individual system should be shared with each discipline prior to fine tuning the design.

(5) **Fine Tune Design:** Individual system designs are 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.

(6) **Verification Simulation:** Verification simulation of the building shall be performed after fine tuning measures have been made. The intent of the performance verification simulation is to ensure the desired performance capabilities have been designed into the building and energy performance has been optimized.

**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 the actual barrier of incomplete design documents through an integrated design and detailing activity.

(7) **Integrated Design and Detailing:** 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). This expertise permits a draw-it-once approach in which engineering drawings double as shop drawings, and in which constructability and fabrication knowledge is included in the design in the earliest stages.

(8) **Coordination and Production Documentation:** During this phase, the integration and interface between systems is evaluated, and a scaled virtual model of the project is developed and communicated prior to the start of construction. Waste due to field conflicts is eliminated, and reliable production plans can be developed from the resulting final dimensional information.

**REEVALUATION OF PROJECT MEMBER ROLES BASED ON COMPETENCIES: CFDPM^HP**

The CFDPM^HP highlights three components of the high performance design process.
These include key cross-disciplinary collaborations, the proper timing for these collaborations, and core competency requirements of each activity. The CFDPM$^{HP}$ 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.

High performance buildings and the integrated processes require a unique set of competencies and skills. A thorough review of competencies has been conducted in an effort to identify the most critical competency requirements (Lombardo and Eighenger 2002). Based on case study comparisons to successful high performance project design teams, and through interviews and focus group discussions at the 1st Annual PACE Integrated Design Roundtable, thirteen individual competencies and five high performance project team traits were identified (ID Roundtable Proceedings, 2003; Katzenbach and Smith 2002). In addition, descriptive roles of team members throughout the design process were developed in recognition of the need to shift leadership of the process during the phases of design. Table 1 provides a list of these competencies, traits, and roles.

Table 1: Key Competency Requirements and Role Definition of the High Performance Building Design Process

<table>
<thead>
<tr>
<th>Individual Competencies</th>
<th>Team Traits</th>
<th>Role Definition</th>
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</thead>
<tbody>
<tr>
<td>Manages Ambiguity</td>
<td>Collective and Mutual Accountability</td>
<td>Leader</td>
</tr>
<tr>
<td>Integrity &amp; Trust</td>
<td>Equally Shared Commitment</td>
<td>Accountable for the completion of the process</td>
</tr>
<tr>
<td>Patience</td>
<td>Complimentary Technical Skills</td>
<td>Consultant</td>
</tr>
<tr>
<td>Priority Setting</td>
<td>Appropriate Resource Allocation</td>
<td>Advisor</td>
</tr>
<tr>
<td>Problem Solving</td>
<td>Effective Communication Paths</td>
<td>Provides input to the process</td>
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<tr>
<td>Timely Decision Making</td>
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<tr>
<td>Creative problem solver</td>
<td></td>
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<tr>
<td>Functional / Technical Skills</td>
<td>Teams Building</td>
<td></td>
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<tr>
<td>Informing communicator</td>
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<td>Seeks continuous improvement</td>
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Figure 3 represents the CFDPM$^{HP}$ for the energy optimization design activities on a high performance university classroom building case study project. The horizontal axis consists of specific key activities comprising specific facets of the level II BDPM$^{HP}$ for energy optimization. The vertical axis houses the functional competency requirements of the high performance building design process. Functional roles of the design team participants are assigned to each competency either on a leader, consultant, or advisor basis and the BDPM$^{HP}$ activities are located in the horizontal axis. Leader responsibilities include ultimate accountability for the given activity and no more than one individual can hold this role. Individuals assigned the role of consultant possesses knowledge or skill vital to making effective decisions for the given activity as well as in-depth project knowledge. The advisor functional role represents one who possesses skills or knowledge.
related to the given activity, but does not possess project specific knowledge with regard to the given activity.

**Figure 3: Level II CFDPM\textsuperscript{HP}: Energy Optimization Activities**

**TESTING METHODOLOGY**

Case study data collection is being performed to evaluate and refine the BDPM\textsuperscript{HP} and CFDPM\textsuperscript{HP}. This research explores current practices dealing with the design of high performance buildings. Case studies were selected that have exceeded energy consumption requirements of ASHRAE 90.1. and are being analyzed after design is complete. Case study projects provide examples that have confirming attributes of both the BDPM\textsuperscript{HP} and the CFDPM\textsuperscript{HP}.

Preliminary analysis has been performed during the conceptual level model development to aid as guiding examples for the model components. Additional case study research will be performed to evaluate and validate the overall level one and level two process models. Projects that implemented high performance processes will be examined to validate the key core competency requirements identified for individuals and the team in the CFDPM\textsuperscript{HP}.

**CASE STUDY APPLICATION: LEARNING BY DOING**

The detailed evaluation of the CFDPM\textsuperscript{HP} is also being performed through a detailed cases study in which the research team will actively manage the design and production planning of an actual building project. The focus of this application will be a 4000SF daycare and early childhood learning center to be constructed on the Northern Cheyenne Indian Reservation. One hundred percent of the design, engineering, production planning, and construction management will be performed by the research team. The project is
targeted for LEED™ Gold Certification, and will utilize state-of-the-art building performance optimization modeling and simulation. Performed completely outside the confines of traditional contractual arrangements, this case will provide a unique perspective of how the design process and design teams function when motivated only by personal satisfaction and dedication to the common goal of a successful project.

**COMPUTER SIMULATION METHODOLOGY**

Testing of the BDPM\textsuperscript{HP} through virtual design team simulation will be performed through the use of the computer software Simvision©. Utilizing the optimum high performance process model and data collection in the CFDPM\textsuperscript{HP} from case studies, the high performance process key activities, discipline participation, and process relationships will be modeled. Test simulations will be measured based on their effectiveness in eliminating rework caused by unnecessary ambiguity, appropriate cross functional collaborations, and effective sequencing of key activities. The computer simulation output will be used to identify alignment of potential problems with actual problems in the case studies, as well as the anticipated impact of rework in the base model.

**PRELIMINARY FINDINGS**

Early case studies used to test the BDPM\textsuperscript{HP} have found the most critical feature of the design process to be an early and accurate definition phase that is highly inclusive of team members and disciplines. The most common problems found on early case study projects are the lack of energy strategy tools utilized early in the design optimization process, a lack of defined tolerances and prerequisites for design decisions, late changes to designs that threaten performance, and a lack of constructability knowledge and competencies during design development and detailed design. The results of this research will directly inform owners seeking to form high performance building teams, as well as design and construction organizations.

**FUTURE RESEARCH**

The next phase of this research includes the development of additional key level II process maps for the BDPM\textsuperscript{HP}. All critical processes and key sub processes of the model will be developed and tested through industry feedback and computer simulation. Key activities that provide the framework for key sub processes will be evaluated and enabling decisions identified. A more robust description of the competency requirements of design disciplines involved in the high performance design process will also be developed and tested. Key relationships between competency involvement and overall project success will be tested on a larger scale of industry members who have participated in the design of high performance buildings.

**CONCLUSIONS**

Current building design process models fail to consider critical components required to efficiently deliver a high performance building. A process model and team competencies for high performance buildings are proposed. Background and design development
models of the BDPM$^{HP}$ and CFDPM$^{HP}$ have been presented. These provide the principle framework for the identification of key attributes and competency requirements of a high performance design process and team. Continued research effort in progress will focus on fully articulating a constructive guide for project teams on high performance building projects.

REFERENCES


