SUSTAINABLE METRICS: A DESIGN PROCESS MODEL FOR HIGH PERFORMANCE BUILDINGS

David R. Riley, Ph.D., Chris S. Magent, M.S., and Michael J. Horman, Ph.D.*

CIB T4 Sustainable Construction

ABSTRACT
Design information for buildings is increasingly uncoordinated because it is formulated by specialists in various disciplines. This negatively affects the "completeness" of construction documents. In addition, significant waste can be found in the value chain of design information from the napkin sketch to the foremen in the field. Such waste includes the duplication of information and the recreation of existing information for alternative purposes and audiences during the design process. Current processes also fail to formally acknowledge the role of specialty contractors in design, and their potential added value to upstream decisions and processes. To achieve true integration between building systems, design processes must be better defined and the necessary interaction between project teams must be more formally articulated. High performance buildings are defined as those that minimize resource consumption during construction, and over their life, and provide healthy and productive environments for occupants through the application of "sustainable" or "green" principles. Application of these principles on building construction projects requires even greater integration and collaboration between the project team members than traditional projects due to the greater levels of complexity involved. Building momentum for the design and construction of green buildings has energized the design community and facility owners. Spurred by this initiative, this paper presents a model for addressing the tensions and interplay between project team members on high performance building projects and describes the development of new metrics for building design processes. The model incorporates modern procurement processes found to be effective on complex green building projects. Potential implications of this model and performance metrics for design are discussed.

Key Words: Sustainable Design, Green Buildings, Process Modeling

INTRODUCTION

Green buildings have many desirable attributes and subsequently are growing in demand. Buildings that minimize resource consumption during construction, and over their life, and provide healthy and productive environments for occupants through the application of "sustainable" or "green" principles are becoming known as high performance buildings. The demand for these types of buildings has in part been fueled by advances in technologies and economic arguments that overcome misconceptions about high first costs. Private entities and public owners are recognizing the worth of investments in long term energy savings, and subsequently are procuring green buildings for speculative office space, healthcare facilities, schools, and homes. There is also a growing awareness of the improvements in worker health, happiness, and overall productivity which are being experienced by occupants of green buildings. As this is better documented, powerful economic incentives are emerging for these types of facilities.

---

* D.R. Riley is associate professor, Department of Architectural Engineering, Penn State University, University Park, PA; C. Magent is Ph.D. student, Department of Architectural Engineering, Penn State University, University Park, PA; M.J. Horman is assistant professor, Department of Architectural Engineering, Penn State University, University Park, PA.

An integrated design process is needed to achieve green attributes, and this places great demand on the design team. The increased interplay between building systems in integrated designs demands increased interaction and communication among design disciplines. In an integrated design process, building systems are designed in parallel, rather than series, so that the cumulative effect of design decisions concerning one system can be evaluated on other systems. This process departs from established "sequential" design processes, where various disciplines contribute to a design with limited interaction with other disciplines. This new design approach presents a major challenge to creating coherent and complete designs, and typically requires increased expenditure of project resources for design services.

What would help this current growing concern is a clear articulation of the integrated building design process for high performance buildings, and a set of metrics that will allow for the assessment and evaluation of the design process. Thus, the goal of this research is two fold. First, develop a clearly articulated process model of design functions, so the process can be evaluated and assessed for improvement. These improvements are identified through an assessment of the value chain of design information, and the application of established principles in waste reduction (lean principles). Next, develop a set of performance metrics for this process, in order to enable validation of the process model through case study assessment.

RELATED RESEARCH AND CURRENT PRACTICE

Design Process Modeling - Several efforts have been made to articulate the building design process, the most thorough of which was the Integrated building Process Model (IBPM) by (Sanvido, et. Al. 1990). Developed using the $IDEF^0$ modeling methodology, (NIST 1993) this seminal work serves as an excellent starting point in the development of a focused process model on the design of high performance buildings. (Reed and Gorden 2000) provide the most extensive description of "integrated design," referring to an inclusive and collaborative effort among various disciplines, found in current literature. 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 charrette, 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. All design specialists must meet to evaluate the merits of different systems and materials.

Green Building Metrics – Several sets of metrics have been developed to assess a building's the level of performance. The LEED™ rating system serves as the first nationally accepted measuring system for sustainability in the United States (USGBC, 2003). Of the five core elements in the LEED™ rating system, the inclusion of indoor air quality and day lighting requirements are perhaps the most powerful, as they elevate the value of green buildings through improvements in worker productivity. (Romm and Browning, 1998) further contribute to the economic argument of green buildings through case studies demonstrating the value of green buildings in increasing worker productivity.

Role of Construction Organizations in Design – The increased popularity of design-build delivery methods and other progressive procurement methods have elevated the role of construction organizations in design. (Riley, et. al. 2003) presents the potential roles of construction organizations on green building projects, in particular through the provision of early and accurate cost projections during the design process. (Gray, 1998 and Gil et. al., 2000) are among the first to articulate the role of specialty contractors in design, and demonstrate examples of this value through case studies. A key observation is made that while specialty contractors may significantly improve the effectiveness of the design and building process, AEC organizations have few mechanisms in place to take advantage of this knowledge.

Current Practice: Challenges Observed in Building Design Processes

Many visible challenges face building design teams. Several of the most prevalent and damaging are described here based on comments and experiences of design and construction professionals.

Team formation and management – Every building project requires a new team to be formed from different companies and disciplines. In many cases, the way some team members are selected creates animosity and distrust before the project even starts.

> "Our industry should be the *best* in the world at forming teams fast, yet we are actually the *worst*"
>
> John Tarpy, Executive Vice President, Centex Construction

The dispersion of team members can also result in design processes taking place without full input from relevant parties. Useful competencies among team members can be inadvertently neglected. The emergence of partnering at the onset of a project as a band-aid for this challenge is not surprising. Partnering rarely happens during the design process however, and falls well short of addressing this challenge. More defined processes are needed to help owners oversee and manage the formation of a functional team.

Fragmentation of Design Disciplines – It has recently been agreed in the design and construction industry that the development of design information for buildings has declined and become increasingly uncoordinated. These changes can and have been attributed to many different factors. The American Council of Engineering Companies has identified decreased educational requirements at Universities, reduced design fees for professionals, poor economic conditions and increased utilization of technology as causes for these changes (ACEC 2003). However, there are many reasons beyond the issues outlined by contributing to this decline in quality, most of which have to do with the fundamental design process and not the individuals developing a building design.

Ambiguous procurement processes – No formal language or guidance on which team members and associated competencies distributed in their organizations should be involved with specific design processes. Currently only loose definitions of various delivery methods are used imply the timing of involvement of consultants and construction organizations. More certainty is needed on the types of procurement methods and related processes for teams that enable high performance building projects.

Undefined roles and competencies – AIA documents define responsibilities among team members for building projects; however they fall short in describing all of the functional competencies needed among project players. We thus have no formal system to assess if processes are being carried out by team members with the appropriate functional competencies. High performance buildings require an even greater set of additive functional competencies than traditional project, and are thus place an even greater demand on the distribution of competencies among team members (Reed and Eisenberg, 2003).

Misalignment of incentives and penalties with functional competencies – The US building industry has a somewhat warped technique for distributing risk, incentives, and accountability. For example, the ultimate accountability for project cost lies with contractor, yet they rarely have input early in the project when the most significant influences on cost are determined. Design professionals charge fees estimated by heuristic assessments of the time needed to devote to a project, and consistently undercharge for services. Specialty contractors possess useful competencies in design, yet typically are only asked to duplicate an existing design in added detail for construction purposes.

RESEARCH PROCESS

A research program has been initiated to reexamine the process by which buildings are designed, with a specific emphasis on the inclusion of processes vital to the construction of high performance buildings. The first two steps in this research process are the focus of this paper, and begin with a model illustrating the required processes and sub-processes required in the design of a high performance building. Next, a set of metrics are presented to assess the design process on case study projects based on the processes performed, the timing of their performance, and the competencies of the project team members included in the process. Once developed, the process model and associated performance metrics will be used to correlate the relationship of projects that follow the model to successful project outcomes. Success will be defined using the project success metrics cost growth, schedule growth, and LEED^{TM} rating system. Initial progress in developing the process model and assessment metrics are described below.

A Building Design Process Model for High Performance Buildings (BDPM^{HP})

A Building Design Process Model (BDPM^{HP}) is being developed to define the individual functional processes required to design high performance buildings. Adopted from earlier process models developed by Sanvido (1990), the BDPM^{HP} reflects additional considerations made for modern procurement practices such as design-build delivery, and specific practices found to be pertinent in case studies of the procurement of high performance buildings. Consisting of four phases, Schematic Design, Design Development, Construction Documents, and Shop Drawings, the BDPM^{HP} acknowledges the need to expand the classic definition of the design team to formally include a champion of the owner's goals, construction managers, manufacturers and specialty contractors for all disciplines including acoustics, information technology, control systems, commissioning agents etc. The most visible indicator of this expanded definition is the inclusion of the shop drawing phase as a formal step in the design process. A brief overview of the BDPM^{HP} and Level 1 processes are described below and illustrated in Figure 1. For each phase, examples of processes considered vital to the design of high performance buildings are provided.

A. Schematic Design: The schematic design process begins with the understanding of the functional requirements of the project, and the establishment of project objectives. At this point, the priorities of the owner are established to guide subsequent decisions in the design process. From these objectives, design parameters are set, and preliminary studies of early concepts should be performed. Early concepts are coordinated and building systems such as envelope and mechanical system types are selected. *Examples of key elements for high performance building during this phase include: site selection and building orientation, and energy modeling of alternate building configurations.*

B. Design Development: In the design development phase, the schematic design is carried forward with more detailed layouts of building systems. More detailed analysis is conducted by specialty consultants, and the performance of these systems are integrated and optimized. Specification describing key project features and performance requirements are authored, and appropriate approvals are obtained on design decisions. *Examples of key elements for high performance buildings during this phase are: detailed energy modeling, day lighting analysis, and energy efficient mechanical/electrical systems selection, and accurate first cost and life-cycle cost analysis of design alternatives*.

C. Construction Documents: During the construction document phase, system dimensions are defined and appropriate manufacturing data such as equipment sizes and capacities are obtained. A detailed set of drawings and specifications, (often referred to as "bid documents" in traditional processes) are generated. Appropriate approvals are acquired, and the design is communicated to construction organizations. *Examples of key elements for high performance building during this phase are: the selection of environmentally friendly materials; detailing that minimizes material waste and allows for deconstruction; and the authoring of performance-based specifications.*

D. Shop Drawings: During the shop drawing process, construction management and specialty contractors must interpret both detailed and performance information for intent. At this point, single or alternative solutions are proposed. The final design decisions are then represented in scale drawings or digital models, and conflicts between systems are resolved. Post-Design documents are generated to represent the actual systems components to be constructed, and final approval is obtained. Finally, the design is communicated to the field. *Examples of key elements for high performance buildings during this phase are: design and constructability suggestions that reduce material use and improve building performance, the selection of environmentally friendly materials based on performance specifications, and the provision of accurate cost projections for alternatives.*

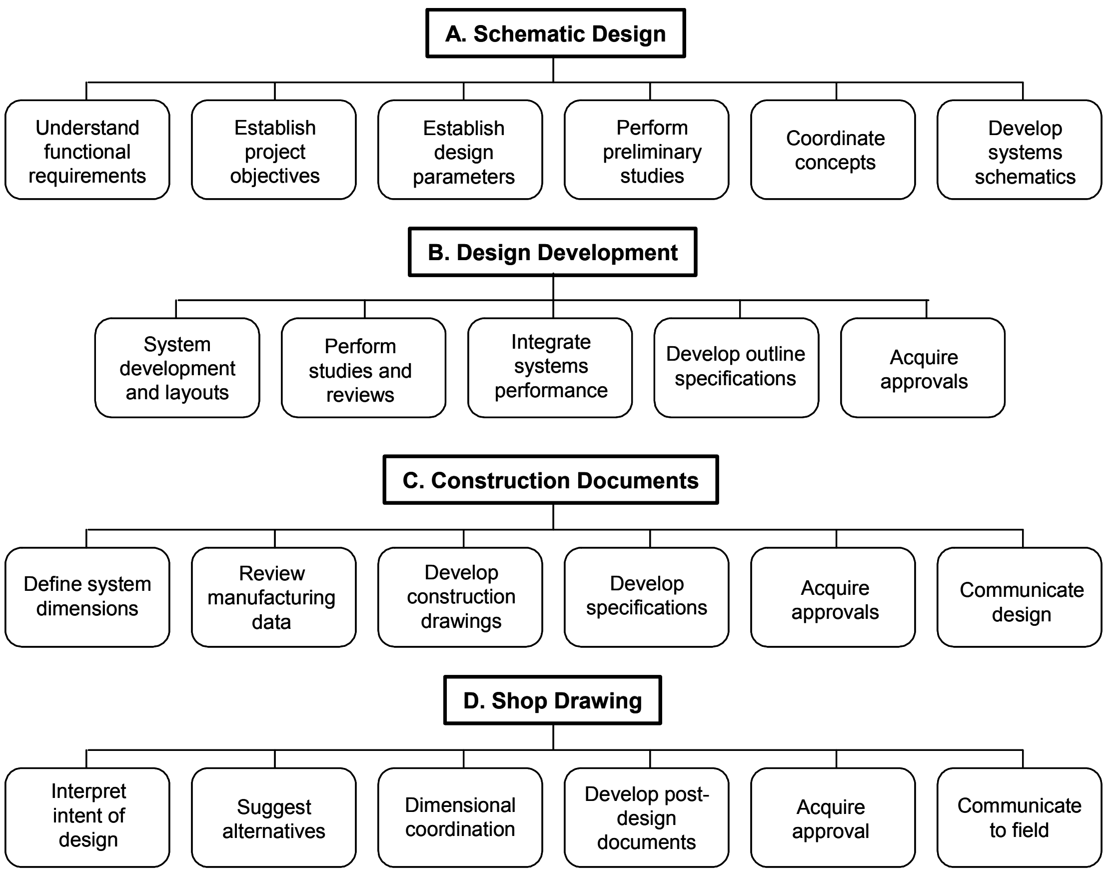

Figure 1: A Building Design Process Model for High-Performance Projects (BDPM$^{HP)}$

The description of the BDPM^{HP} presented here represents the only Level 1 detail. Levels 2 and 3, currently under development, provide detailed definitions of the process, and key features of high performance building design to be articulated. For example, energy modeling and assessment of locally available materials would be represented as sub-processes of the design-development phase. In addition, Levels 2 and 3 allow for the sequence and priorities of more detailed processes to be defined.

Validation of Model: Metrics to assess the BDPM^{HP}

Validation of the BDPM as a guide for high performance building projects will be performed using a combination of established metrics for project success and new metrics developed to assess the performance of design processes on case study projects. Validation of the model will be determined by demonstrating that projects having a close fit to the BDPM^{HP} are successful in terms of the achievement of quality objectives, acceptable cost and schedule growth, and their score based the LEED^{TM} rating system.

A key objective of this research is the development of metrics to assess the design process. For this purpose, and assessment tool has been developed called the Cross-Functional Design Process Map (CFDPM). The primary purpose of the CFDPM the assessment of how design processes are aligned with functional competencies distributed among project team members. Two illustrative applications of the CFDPM are provided on figures 2 and 3. The at the summary level presented here, the tool provides a graphical illustration of which team members play a role in each design process, and a description of that role as either leader, consultant, or assistant.

Figure 2 illustrates an application of the CFDMP for a case study project in which a traditional design-bid-build process. Design processes are represented at the top of the chart, and functional competencies are represented by the various team members on the left. Vertical lines under each design process are used to indicate which team members (and associated competencies) are included in the process, and at what level of involvement (leader, consultant, or advisor) they play in that process.

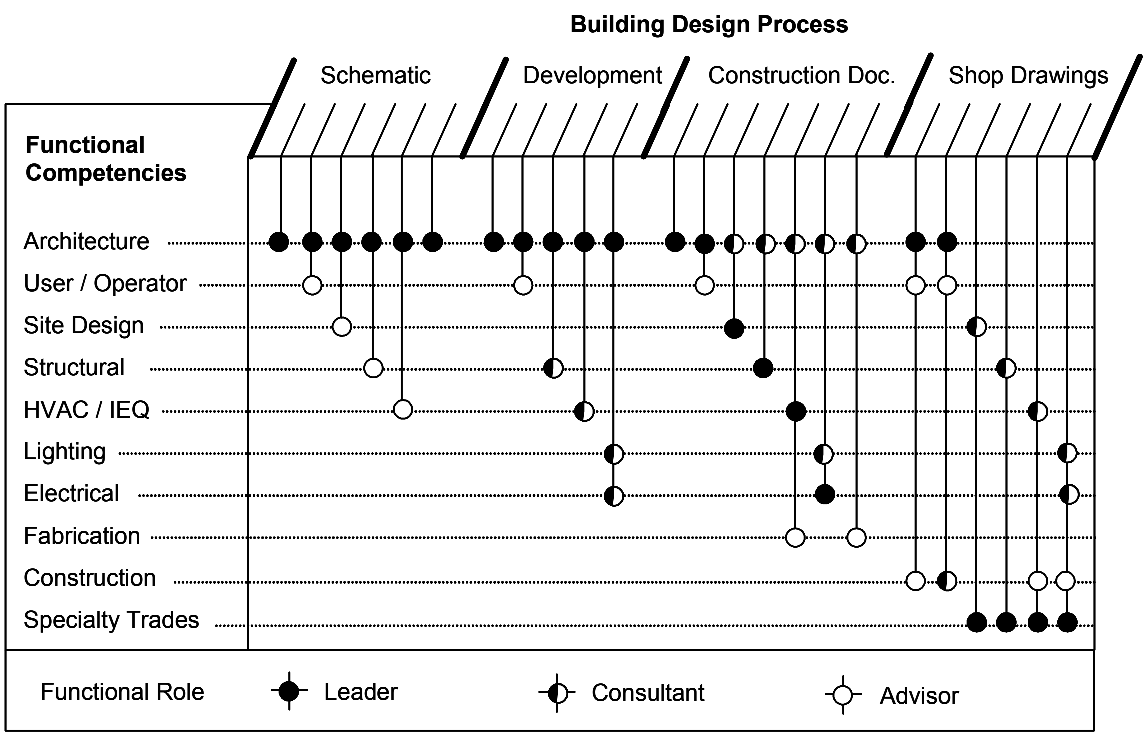

Figure 2: Cross-Functional Design Process Map (Traditional Project Delivery)

The CFDPM in figure 2 illustrates processes in the schematic design phase being performed under the leadership of the architect, with functional competencies of site, structural and mechanical design included at an advisory level. In the design development phase, the role of these functions is elevated to a consultant. During the construction document phase, team members with design competencies in specialty areas take the lead in developing drawings and specifications (bid documents) with advisory level input from manufacturers. During the shop drawing phase, construction management and specialty contractors competencies are introduced in leadership roles, as shop drawings are developed, and cost information is provided. Design functions in specialty areas remain involved at a consulting level. Throughout this example, most processes are performed by one entity, with limited or no cross functional interaction between the design team.

Case 1 Results: The project modeled in this case was intended to be a high performance building with a goal of achieving a Gold LEED certification. While not completed at the time of this publication, the project has demonstrated several difficulties. The design process has been highly criticized by the intended occupant of the building. The design has taken over a year longer than expected with immeasurable ill effects upon the intended occupants, and initial construction estimates vastly exceeded established budget parameters.

Figure 3 illustrates an application of the CFDPM for Case 2, on which a more integrated design process was implemented on a high-performance building project. In this case, a fully functional design team was formed early in the project including specialty consultants, experts in high performance building design, a construction manager, and both mechanical and electrical (design-build) specialty contractors. More extensive interaction among team members and functional competencies is evident in many design processes as indicated by the increased number of nodes present on the CFDPM for the project. More extensive functional design competencies are engaged during schematic design, and advisory roles of construction managers and specialty contractors are indicated to provide cost and constructability input early in the design process. The design development and construction document phases include elevated levels of consulting roles and multiple functional competencies associated with many design functions.

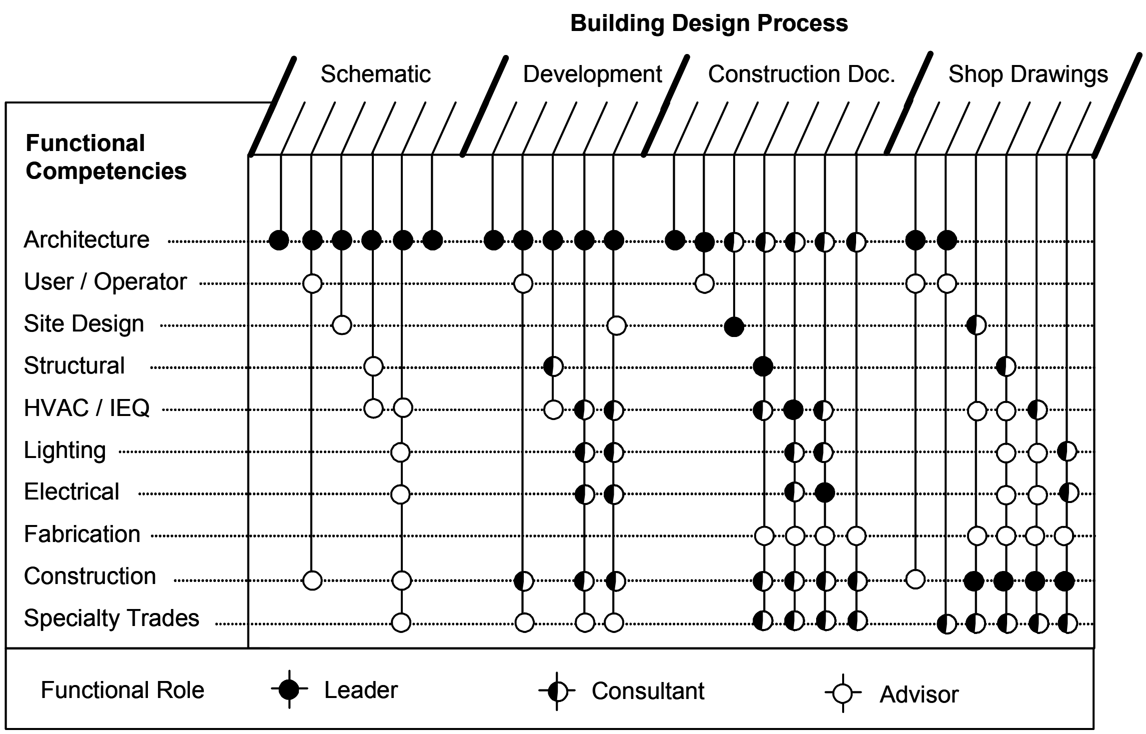

Figure 3: Cross-Functional Design Process Map (Integrated Project Delivery)

Case 2 Results: The project represented in case 2 (figure 3) has experienced positive and observable success in achieving its goals for a high performance facility. The design solution has been revered by the project team as a highly appropriate and effective solution. The design has dramatically reduced material use, space efficiency, and energy performance over initial concepts. The project team is currently seeking additional projects to pursue together, in recognition of how effective they have worked together.

The mapping of building project design processes using the CFDPM permits an assessment of the performance, timing, and responsibility of design processes. The two illustrative cases above demonstrate how two very different design processes can be represented at a summary level. Current research efforts are focuses on the appropriate levels of communication and interaction between project team members and their related functional competencies, and a set of rules that define how these roles are distributed on successful projects; for example, a rule stating that all processes in the model require a complimentary functional competency from at least one team member. Additional rules will be used to help define responsibility and accountability for design processes, for example: "Each functional role in the process should be affiliated with at least an advisory role by the entity contracting for that functional role," meaning that is a specialty contractor is performing a consulting function for a given design process, than the general contractor that hired them should also be represented at an advisory or consulting level role for that process.

FUTURE RESEARCH

The next phase of this research (in progress) includes the full scale development of the $BDPM^{HP}$ to define all processes and sub processes required in the design of high performance buildings. Applications of lean theory will be incorporated in the development of this full-scale model, and considerations for the management of the design process, and communication patterns between team members will be articulated. In addition, a more robust description of the functional competencies required on project teams will be defined. Next, a full set of rules will be developed for the assignment of roles between project team members and design processes, and a base model of recommended roles will be developed for the design process. Case studies of building projects will then be performed to validate the model as a guide for the design process on high performance building projects.

CONCLUSIONS

Current models of the building design process fail to articulate the processes and sub processes required in the design of high performance buildings. An initial model of the design process and associated competencies has been designed and is currently under development. Metrics to assess project design processes have also been designed. Initial applications of this model and associated metrics have been found useful in assessing design processes on case study projects. Continued research effort in progress will focus on fully articulating a constructive guide for project teams on high performance building projects.

ACKNOWLEDGEMENTS

The research efforts described in this paper are supported by the Partnership for Achieving Construction Excellence (PACE) at the Pennsylvania State University.

REFERENCES

American Council of Engineering Companies (2003). "A Guideline Addressing Coordination and Completeness of Structural Construction Documents" *Case Document 962D*.

Gil, N., Tommelein, I. D., Kirkendall, R.L., and Ballard, G. (2000). "Contribution of Specialty Contractor Knowledge to Early Design." Proc. Eighth Annual Conference of the International Group for Lean Construction (IGLC-8), 17-19 July, held in Brighton, UK.

Gray, C., and Flanagan, R. (1989). "The changing role of specialists and trade contractors," Ascot, CIOB.

National Institute of Standards and Technology (NIST) (1993). Announcing the standard for integration definition for function modeling (IDEF0). Gaithersburg, MD, National Institute of Standards and Technology (NIST). 108.

Reed, W., Gordon, E. (2000). "The Integrated (Sustainable/Whole System) Design and Building Process"

Reed, W., Eisenberg, D. (2003). "Regenerative Design: Toward the Re-Integration of Human Systems with Nature"

Riley, D. R., Drilling, J. and Pexton, K. (2003) "The role of the contractor on green building projects" Proceedings of the CIB 2003 International Conference on Smart and Sustainable Built Environment, Brisbane Australia.

Romm, J, Browning, W (1998). "Greening the Building and the Bottom Line – Increasing Productivity Through Energy-Efficient Design"

Sanvido, V. E., S. A. Khayyal, et al. (1990). An integrated building process model. University Park, PA, Computer Integrated Construction Research Program.

USGBC (2003). " The Leadership in Energy and Environmental Design (LEED) rating system," The US Green Building Council, www.usgbc.org.

Zabelle, T.R., and Fischer, M.A. (1999). "Delivering value through the use of three dimensional modeling," Proceedings of the International Conference on Concurrent Engineering in Construction (CEC99), August, Espoo, Finland.