TECHNICAL PAPER

Assessing Project Delivery for Sustainable, High-Performance Buildings Through Mixed Methods

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Abstract

Project delivery processes that describe contractual agreements among project participants, timing their activities and levels of involvement have long been subjects for construction management research. Dominated by quantitative methods, this research topic requires large sample sizes mainly due to the extensive number of potential variables arising from the project-based nature of construction. The recent and growing trend in the industry towards sustainable and high-performance building construction introduces added complexities in the project delivery process and challenges research due to the limited population of completed environmentally sustainable buildings. This study presents a combined use of quantitative and qualitative methods, also called mixed methods, as a useful way to respond to the research challenges. This research first quantitatively selects important variables of project delivery from a sample of sustainable, high-performance office buildings ($N = 40$) and then tests those variables with the analyses of selected case studies. The results of this exploratory study are important to expanding research in the delivery of sustainable and high-performance building projects and the methods required to expand the understanding, validity and reliability of this research.

■ *Keywords* – Green buildings; high performance; mixed methods; project delivery; qualitative; quantitative; sustainability

INTRODUCTION

The sustainable building market is growing. Estimates indicate that this market sector will reach $96–$140 billion by 2013 (Smart Market Report, 2007). As the market grows, the architecture, engineering and construction (AEC) industries also realize that sustainable building projects, especially those including high-performance energy and indoor environmental quality systems, pose additional requirements in their delivery (planning, design and construction) processes. The added requirements of such projects are commonly understood to require integrated project delivery, early involvement of key project parties, owner commitment to sustainability and use of simulation tools (Riley et al., 2004; Lapinski, 2005; Riley and Horman, 2005; Beheiry et al., 2006; Horman et al., 2006). Emerging concepts such as integrative design (Reed and Gordon, 2000), the Whole Building Design Guide (WBDG, 2009) and integrated project delivery (AIA, 2009) in the AEC industry also confirm the importance of understanding the project delivery

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attributes on which multidisciplinary teamwork is required. These additional requirements for delivery of sustainable, high-performance buildings need investigation to identify the projects' success factors to better inform the features of project delivery that most highly influence project outcomes. With this motivation, the goal of this research is *to identify the metrics for evaluating project delivery of sustainable, high-performance buildings.*

This research includes methods that deviate from those traditionally followed to study project delivery methods that have been dominated by purely statistical methods. The challenges of collecting construction project delivery data coupled with the limited number of completed green buildings and exemplary projects limit the accumulation of ideal sample sizes. In response, this research focuses on the inclusion of descriptive *qualitative* project delivery attributes in addition to the *quantitative* metrics to identify the best practices leading to improved performance on sustainable and high-performance building projects. This research expands the variables to be investigated leading to new opportunities to identify valuable relationships between independent and dependent variables of project delivery. To achieve its objectives, this study adopts mixed methods. Initially a quantitative analysis examines project delivery data from 40 high-performance building projects. Subsequently, the research introduces a qualitative analysis from case studies to support the findings of the quantitative analysis and to draw additional conclusions.

BACKGROUND

Sustainable, high-performance building design pursues minimal resource consumption, energy-efficient envelopes, mechanical and lighting systems coupled with improved indoor environmental quality to enhance occupants' health and productivity. Adoption of these buildings is becoming more widespread due to their potential to reduce energy costs and to improve the health and productivity of occupants. The need for optimizing all systems and design in these buildings adds complexities, for example, the increase need for team interaction, increased need for specialized system expertise and the introduction of new technologies. Adjustments in delivery processes are necessary to help facilitate, manage and improve the effectiveness of these project team transactions.

Project delivery processes define the type and timing of contractual agreements among a project's participants and their working relationships and have long been the subject of research. Traditionally, quantitative methods utilizing sample sizes ranging from 12 to 351 dominate research and larger sample sizes increase the significance of findings (Bennett et al., 1996; Pocock et al., 1996; Konchar and Sanvido, 1998; Molenaar et al., 1999; Ibbs et al., 2003; Hale et al., 2009). Recent research on project delivery presented the use of qualitative methods such as content analysis, comparative analysis (Pulaski, 2005), process mapping (Lapinski et al., 2006; Klotz, 2008), pattern matching, cross-case synthesis and explanation building (Magent et al., 2009; Pommer and Horman, 2009). Taylor et al. (2009) supported the use of case studies in construction research to study realistic phenomena, thereby allowing witness to decisions made about real issues that impact on factors such as a time, cost, quality and safety. Zimmerman (2005) indicated that quantitative research is objective while qualitative research, dealing with beliefs and individuals, is subjective; together these methodologies can provide a comprehensive insight into a research problem. Recently, especially in the social sciences, where one type of research methodology provides an inadequate response to the research question, researchers combine quantitative and qualitative methods resulting in mixed method research. Three different approaches (e.g. QUAN-qual, QUAL-quan) apply differing weights to the quantitative and qualitative components to jointly respond to the research question (Gay et al., 2005).

METHODS

The characteristics of the current research affirm the use of mixed methods to respond to the research question: 'What potential metrics can be useful in evaluating the project delivery of sustainable, high-performance buildings?' The procedures followed and their outcomes in each step in this research are illustrated in Figure 1.

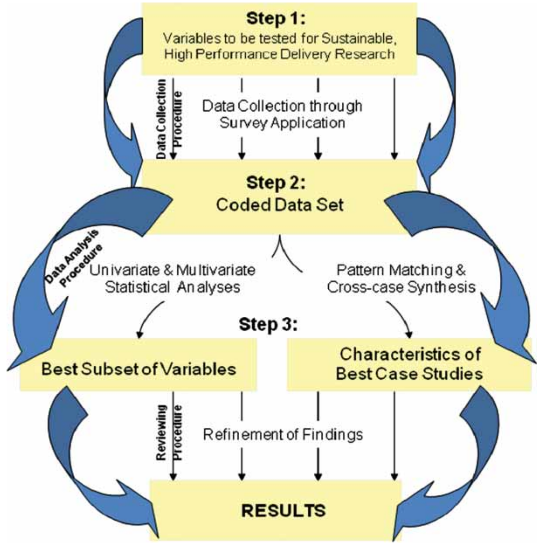

FIGURE 1 Process map of the research utilizing a QUAN-qual methodology

TABLE 1 A summary of the study variables identified to test the research question

INDEPENDENT VARIABLES	CONTROL VARIABLES
Owner commitment	Project type and complexity
Project delivery system	Building use, size and location
Project team procurement	Pool of qualified contractors
Contract conditions	Regulations/legal constraints
Design integration	Onerous contract clauses
Project team characteristics	Building characteristics
Construction process	Sustainable, high-performance features
Dependent variables (performance metrics)	
Schedule performance	Cost performance
Quality performance	Levels of sustainability and high performance
Safety (OSHA measures)	

The study employs a QUAN-qual model (Gay et al., 2005), where following the data coding (1) a hypothesis testing procedure through statistical analyses, and (2) qualitative data analysis and interpretation to elaborate the findings of the first phase are conducted. Extensive literature and industry reviews and a pilot study assisted the research's first step where the preliminary set of variables was identified. These variables (represented in Step 1 of Figure 1) include: (1) project delivery attributes classified under independent and control variables, and (2) performance metrics as dependent variables. A summary of more than one hundred variables identified for this research appears in Table 1 (detailed description of these variables, their subcategories and calculation of scores for each project according to these categories appear in Korkmaz et al., 2007).

A comprehensive survey (Korkmaz, 2007) to collect data on the preliminary list of variables, developed from earlier research efforts (Konchar and Sanvido, 1998; El Wardani et al., 2006), and then revised based on industry professionals' feedback, reached its final form after pilot testing. Newly constructed office buildings in the USA that received a green building certification are the target population for collecting data. This study's database of potential green office buildings arises from contact with industry partners and a search of public domain green building resources, such as High Performance Building Database (DOE, 2009) and the List of Certified Leadership in Energy and Environmental Design (LEED®) buildings (USGBC, 2009). The database of identified building projects includes 209 office buildings. Contact through phone calls and e-mail with project managers (i.e. working for owners, designers, and/or contractors) of these buildings solicited their participation. Once the respondents agreed to participate, they received an e-mailed link to an online survey used for collecting data. Follow-up correspondence attempted to increase the response rate and reduce the non-response to questions in partially completed surveys. Cross-referencing among various project participants, documentations provided by the respondents and the case study information appeared on the Internet and in industry publications all helped to verify the collected data. On completion of data collection, spreadsheets of transferred and fully coded data allowed initiation of data analysis.

QUANTITATIVE DATA ANALYSIS

The first analysis entailed examination of the associations between project delivery attributes and performance metrics. A statistical software package performed these analyses using univariate and multivariate analyses. The univariate analyses, one-way ANOVA (i.e. analysis of variance), ascertained whether or not means-dependent variable values differed according to the levels of categorical independent variables. Regression analysis detected associations between dependent and continuous independent variables at this stage. The multivariate analysis included all significant independent variables selected in the univariate analysis (P value < 0.05) and the control variables for one dependent variable at a time. At this stage, ANCOVA (i.e. analysis of covariance) was utilized due to the mixed types of data: categorical for independent variables and continuous for dependent variables (Cho, 1997).

The extensive number of variables to be investigated, numerous levels associated with some of the independent and control variables, and limited sample size of the study hindered the computation of the statistical analyses in the quantitative analyses.

QUALITATIVE DATA ANALYSIS

The study continued with qualitative data analysis to triangulate the quantitative findings and draw additional lessons from the exemplary projects. Multiple cases are influential in theory building since they permit replication and validation of propositions through extension of theory among individual case studies (Eisenhardt, 1989). The adopted multiple-case approach for this stage employed several tactics to satisfy research quality requirements, based on Yin (2002) as presented in Table 2.

Pattern matching and cross-case synthesis analytic techniques analysed the evidence in the case study approach.

TABLE 2 Case study tactics adopted in the research to satisfy the research quality

TESTS	CASE STUDY TACTIC	PHASE OF RESEARCH IN WHICH TACTIC OCCURS
Construct validity	• Use multiple sources of evidence	Data collection
	• Establish chain of evidence	Data collection
Internal validity	• Do pattern-matching	Data analysis
	• Do explanation-building	Data analysis
	• Address rival explanations	Data analysis
	• Use logic models	Data analysis
External validity	• Use theory in single case studies	Research design
	• Use replication logic in multiple case studies	Research design
Reliability	• Use case study protocol	Data collection
	• Develop case study database	Data collection

Source: Adopted from Yin (2002).

PATTERN MATCHING

This method ascertained whether or not project delivery attributes can influence performance outcomes using similar case study pairs. Guided by the research propositions developed from the literature and using accepted practices for estimation, seven selected pairs of projects from the study sample are within 20% of each other's size and cost, and therefore became pairs for comparison. Subsequently, the researchers:

1 Assigned scores to each of the case study performance metrics using a qualitative scale. Criteria for assigning scores to performance metrics were the result of detailed examination of each dependent variable for performance metrics. Three dependent variables determine each metric. For example, cost growth, unit cost, and intensity were the dependent variables used to identify the cost metric. Calculation of descriptive statistics for each dependent variable examined the mean and median values for the selected case studies. Most of the

data sets for the dependent variables were not normally distributed; therefore, decisions regarding the criteria to use to develop the scores arose from histograms (Korkmaz, 2007).
2 Categorized the selected case study pairs under each independent variable.
3 Determined whether or not any differences occurred in the overall performance metric scores of case study pairs based on the changes in the project delivery attributes.
4 Performed pattern matching using different case study combinations.
5 Calculated aggregate scores of the projects that carried project delivery attributes in favour of or contradictory to a research proposition and assigned a 'Aggregate Score (+)' or 'Aggregate Score (−)' for that independent variable, respectively.
6 Interpreted the findings occurred by matching the change in the project delivery attributes with the change in the (a) overall project performance scores of the case study pairs, and (b) the aggregate scores of all pairs. The case study evidence favoured a research proposition if the majority of the case study pairs supported it. The magnitude of the difference between aggregates (+) and (−) for a given independent variable reflected the importance of the related research proposition. An example of the method used to interpret the findings from the pattern matching approach appears in Table 3 for testing the proposition: 'Higher design integration leads to better performance outcomes in sustainable, high-performance building projects'.

CROSS-CASE SYNTHESIS

This method enabled comparisons between case studies that exhibit 'exemplary' and 'less desirable' overall performance and determined whether exemplary studies present more of the project delivery attributes. To perform this analysis the researchers:

1 Identified the criteria to distinguish exemplary projects from the others. Projects scoring over 80% in sustainable, high-performance categories and achieved less than 5% cost growth received evaluation of exemplary; conversely those projects scoring less than 50% in sustainable, high-performance categories and had greater than 15% cost growth received evaluation of less desirable performance. One exemplary project and two less desirable projects were selected from the case study database for this analysis.
2 The study compared these two groups of case studies and identified the project delivery attributes that differentiated in the two groups. Table 4 illustrates the method adopted to conduct the cross-case synthesis.

RESULTS

The final data set included 40 green building projects, of which majority are commercial offices. Nearly half of the projects are less than 50,000 square feet and about one-fifth range between 50,000 and 150,000 square feet. There is an equal distribution of private and public owners in the data set. Of all owners,

TABLE 3 An example to illustrate the pattern matching analysis procedure

PROCESS INDICATOR # 5: DESIGN INTEGRATION	CATEGORIES	PROJECT CODES	COST	TIME	QUALITY	LEVELS OF HPG	OVERALL SCORE
More (+)	1	Project 1	1	0	1	1	4
Less (−)		Project 2	−1	−1	0	0	−2
More (+)	2	Project 3	0	1	1	0	2
Less		Project 4	0	−1	0	0	−1
More (+)	3	Project 5	1	1	0	0	2
Less (−)		Project 6	0	0	1	−1	0
					Aggregate score (+)		8
					Aggregate score (−)		−3

Representative scores under column titles from 'Cost' to 'Levels of high-performance green (HPG)': −1 = Poor; 0 = Avg; 1 = Good.

TABLE 4 Criteria for interpreting the cross-case synthesis

PROJECT PERFORMANCE	PROJECT CODES	PROJECT DELIVERY ATTRIBUTES – ALIGNMENT W/ PROPOSITIONS						
		OWNER COMMITMENT	PROJECT DELIVERY	PROJECT PROCUREMENT	CONTRACT CONDITIONS	DESIGN INTEG.	TEAM CHARAC.	CONSTR. APPL.
Exemplary	Project 1	√	√	√	√	√	√	√
Less desirable	Project 2		√					√
	Project 3	√		√		√		

85% directly occupy the study buildings. The project delivery systems adopted for these projects represent 40% construction management at risk, 35% design-bid-build and 25% design-build.

QUANTITATIVE RESULTS

The findings of the quantitative analysis include (Korkmaz et al., 2010)

- Earlier involvement of commissioning agents in projects and project size affect construction speed positively.
- Timing of contractor's involvement in the project delivery process affects both cost growth and delivery speed.
- Owner type (i.e. developer, public and private) affects construction and delivery speed and cost growth showing better results for developers.
- The majority of the identified variables appeared to be useful for further investigation showing significance (at P value < 0.2 or P value < 0.05) with at least one of the dependent variables.

Power analyses conducted with the collected data verify the need for larger sample sizes that reach up to 500–600 for significant outcomes at 95% confidence level in this area. At this point, use of alternative methodologies to support the study findings and expanding the potential lessons learned from the data set are essential.

QUALITATIVE RESULTS

Qualitative data analysis triangulated the results of the quantitative analyses, improved the lessons learned from the same data set and helped identify additional process-related variables.

The pattern-matching approach results provided support for four of the identified independent variables for successful outcomes in sustainable, high-performance building projects, as presented below in the order of their importance.

Contract conditions: Negotiation should be used in the team selection process. Owners should hold contracts for primary project participants (e.g. designer, contractor, mechanical and electrical subcontractors and LEED® Accredited Professionals) to orchestrate the green certification process. Including the specific 'green' requirements and/or the level of LEED® certification to be achieved in the contracts can also lead to better project outcomes.

Owner commitment: Owners should be the driver of building 'green' and introduce 'green' as early as possible in the delivery process.

Integrated design: Early involvement of project participants and use of energy and lighting simulations in the process are essential attributes for better design integration.

Project delivery systems: Construction management at-risk and design-build delivery systems result in higher overall success than design-bid-build.

The remaining project delivery attributes were not rejected through the pattern-matching approach since the case studies did not yield contradictory results. However, due to the lack of positive evidence, the determination is that inadequate support existed for those.

Cross-case synthesis of the exemplary and less desirable case study groups show that about half of the project delivery attributes differed between the two groups. The process indicator-related characteristics observed in the exemplary case study, as opposed to the lower-performing cases are as follows:

- 'Green' achievement was an owner-driven pursuit.
- 'Green' was introduced early in the process (at the pre-design stage).

- The project was delivered under design-build process.
- A sole-source selection of the design-builder and the best value source for mechanical and electrical subcontractors were used, rather than the low bid.
- Selection of the design-build team was through negotiation.
- A design-build, mechanical and electrical team was awarded the mechanical–electrical–plumbing work package.
- Achievement of the project's 'green' goals was included in the design-build team's contract.
- All important project parties, including the commissioning agent and the consultants, had early involvement in the process (at the early design stages).
- The highly integrated design process utilized green design charrettes at least twice with the involvement of all major project parties.
- Simulation tools were utilized starting early in the design process (i.e. energy simulation tools during the schematic design stage and lighting simulations during the conceptual design stage).

Open-ended questions within the applied survey and interviews conducted with the respondents also clarified some of the research findings. In most of the projects, no matter the ultimate degree of performance, owners' commitments to 'green' features and the timing of introducing 'green' concepts to projects were among the most important project delivery attributes for project success. Many of the respondents mentioned that a contractor's involvement early in the process and a value engineering approach were essential for achieving projected sustainable, high-performance goals with lower budgets. Participants' responses also indicated that integrated design to be one of the most important delivery attributes. Additionally, design-build was pronounced to be an efficient project delivery system in contributing to the integrated design process, and contractors' earlier input gained mention from most respondents. Several other process-related variables, some already included in this study, were mentioned by at least one of the respondents. A summary of those variables are as follows:

- In pursuing best-value source selection for project teams' procurement, a project's green specifications should be included in the request for proposals and project teams that can commit to more of the given specifications at a given budget should be selected.
- Third-party commissioning agents should test building envelopes for insulation, thermal and moisture resistance quality.
- Design-build mechanical and electrical contractors should be hired as subcontractors to enable higher levels of sustainability and high performance – their early involvement in the design process is important for ensuring optimum mechanical and electrical systems' designs at minimum costs.
- Designers' and builders' relationships should not end upon completion of the construction. They should work with facility managers to ensure that the building operates at maximum performance. Designers' and builders' input might be needed to upgrade buildings to reach expected, designed performance levels during the occupancy phase.

CONCLUSIONS, DISCUSSIONS AND FUTURE RESEARCH

Utilization of mixed methods in this research helps to expand knowledge during the early stages of an emerging research field while the pool of projects available for study remains limited. Results of quantitative and qualitative analyses show that the process indicators defined in this research on sustainable, high-performance building projects' delivery are meaningful in generating better project performance outcomes. Specifically, owner commitment, project delivery system, team procurement, contract conditions and design integration (e.g. timing of project participants' involvement such as contractor, commissioning agent, mechanical and electrical contractors) are identifiably useful project delivery metrics. The patterns observed at this phase of the research provide important lessons learned and can be generalized for the emerging green building population in the future as more data sources can be identified in the field.

The collective evaluation of performance outcomes is useful in this research field to truly understand the features of successful projects and their delivery attributes as project teams may have sacrificed performance in other aspects of performance such as cost to reach a certain level of sustainability certification. As such, focusing on only one performance metric at a time in the analysis of such data can result in missing important and informative patterns.

This research also helps refine the knowledge base about the project delivery attributes that matter for successful outcomes, and demonstrates the challenges in data collection and analysis. The power analyses conducted with the data collected in this study indicate that larger sample sizes (e.g. $N = 500$) yield the desired levels of statistical power in sustainable, high-performance building project delivery research. Future research should include efforts to effectively collect data, methods to maximize study of the response rate in this field and alternative methods of analysing limited research data. These collective efforts can help further validate the project delivery attributes that influence project performance outcomes and guide the AEC industry in the pursuit of delivering successful, sustainable, high-performance projects.

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