AEC+P+F INTEGRATION WITH GREEN PROJECT DELIVERY AND LEAN FOCUS

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ABSTRACT

With the launch of the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) rating system, new building construction in the United States has rapidly begun adopting this guide as the standard for sustainable building. The rating system profoundly alters the design and operation of buildings, however, to date, little has been documented on the cumulative effects of the rating system across different phases of the project lifecycle: planning, architecture/design, engineering, construction and operational facility management (AEC+P+F). Further, the ability to gain efficiencies in the building phase itself is still unknown. Implications of the delivery system in LEED® attainment also have not been clearly associated with the level of AEC+P+F integration. To pursue this goal, project participants are becoming involved earlier in the process; information exchanges take place throughout the project lifecycle; and the results of those frequent exchanges impact the value to the owner through focus on attainment of a particular green rating score. These features are configuring a framework for green project delivery. This framework approaches lean thinking by generating value to the owner, improving the flow of information, and transforming the inputs required for the selection of materials and systems, to outputs in the form of a sustainability rating certification.

This research focuses on exploring associations between LEED® criteria, project lifecycle, the stakeholders' interests, lean process improvements and typical delivery systems used in building construction. The paper proposes a matrix of weighted indexes to explain and provide increased collaboration among project participants, improved efficiency throughout the project lifecycle, and new techniques which may be incorporated into the construction process.

KEYWORDS

AEC+P+F Integration, LEED® rating, project lifecycle, lean processes, Integrated Project Delivery

INTRODUCTION

Sustainable or "green" buildings are now recognized for more efficient resource usage in areas of energy, water and materials. Most buildings that are built to standard codes do not fulfil these same efficiencies. It has also been found that green buildings can contribute to improved employee health, comfort, and productivity in the workplace. Throughout the lifecycle of the building these efficiencies provide opportunities for improved integration and processes. With the launch of the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) rating system, new building construction in the United States has rapidly begun adopting this guide as the standard for sustainable building. The rating system profoundly alters the design and operation of buildings in areas of energy, water and materials use, indoor health, occupant recycling programs, mass transit access, landscaping, construction waste management, and overall maintenance. To date, little has been documented on the cumulative effects of the rating system across different phases of the project lifecycle: planning, architecture/design, engineering, construction and operational facility management (AEC+P+F). The traditional AEC industries plus planning and operational facility management all contribute to an integrated building lifecycle and are included in the proposed analysis. Further, the ability to gain efficiencies in the construction phase itself is still

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unknown. Implications of the delivery system in LEED® attainment also have not been clearly associated with the level of AEC+P+F integration.

This research aims to determine associations between LEED® criteria, project lifecycle, stakeholders' interests, lean principles and improvements to the delivery systems used in building construction. A planned validation of results using expert opinions from the different disciplines will be added in this research next phase for improvement and industry acceptance. A matrix of weighted indexes is proposed and presented to explain current interactions of project participants and integration of stages throughout the project lifecycle. The matrix provides a visual model to generate insights for additional avenues of collaboration, improved efficiency and new techniques which could add to the improvement of construction processes.

BACKGROUND

Historically, the procurement of sustainable buildings in the U.S. has been justified only if its final cost is within a reasonably small percentage of the traditional cost. Projects also need to recuperate costs within a specified number of years. Pearce, et al. (1989) and Gottfried (2003) found that measures of project value or return on investment have been considered important in feasibility analysis of a sustainable project. Recent research is also helping to overcome the concern of cost increases for green projects with validation that early involvement of all major stakeholders, including the contractor, engineers, and facility manager, results in projects that can maximize efficiencies to eliminate unnecessary cost. Some projects have been found to be cost neutral or cost negative for sustainable buildings (Riley, et. al. 2003). Along with normal project objectives, a new, additional objective for the project team is the achievement of a minimum score that provides the desired sustainability certification. The payback analysis procedure is counter to the consensus in the environmental research community concerning lifecycle assessment as the primary legitimate basis on which to compare alternative materials, components and services.

Previous studies identified several drivers of change in the building construction industry as a response to new sustainability initiatives (Augenbroe and Pearce 1998). Some of these drivers include but are not limited to: energy conservation measures, land use regulations and urban planning policies, waste reduction measures, resource conservation strategies, indoor environmental quality, environmentally-friendly energy technologies, reengineering the design process, proactive role of materials manufacturers, better ways to measure and account for costs, adoption of performance-based standards, product innovation and/or certification, adoption of incentive programs, education and training, and recognition of commercial buildings as productivity assets. This list provides initial information to address the importance of the delivery system and the integration of the project lifecycle in the conception of building sustainability.

In addition to the USGBC LEED® guidelines, there are other existing assessment methods, including the U.K. 'Building Research Establishment Environmental Assessment Method'—BREEAM (Baldwin et al. 1998); the Canadian 'Building Environmental Performance Assessment Criteria'—BEPAC—program (Cole et al. 1993); the 'Green Building Challenge'—GBC assessment framework (Cole and Larsson 1999); and the Hong Kong 'Building Environmental Assessment Method'—HK-BEAM (CETC 1996). All of these guidelines contain similarities and dissimilarities regarding environmental issues such as minimizing construction waste, salvaged materials, energy use, preservation of soil and existing trees, wastewater discharge, noise during construction, hazardous materials, etc. (Cole 2000).

The decision-making matrix for LEED®–New Construction 2.2 (USGBC 2007) provides information on the project stakeholders who are required to be involved with specific credits and prerequisites in the overall LEED® rating table. To fully consider the nature of the project lifecycle, decisions must consider impacts not only during pre-construction, but across all the other project stages including construction, commissioning and close out, operation and maintenance, and decommissioning. Due to this change in the involvement of stakeholders in the project, LEED® attainment may be viewed as a catalyst for the integration of the project lifecycle, including architectural planning and design, engineering analysis and design, construction, and

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facility management (AEC+P+F). This statement provides a number of research questions: 1) Is there a relationship between LEED® attainment and AEC+P+F integration? 2) Assuming that LEED® can contribute to AEC+P+F integration, can the latter be measured? 3) Are current delivery systems adequate for building projects pursuing LEED® certification? And 4) Is there a new requirement for a novel delivery system?

Based on a detailed analysis of the project lifecycle under a common delivery system used for LEED® certified buildings, and on the rating system criteria itself, a matrix is proposed. The matrix contains all the interactions that take place at every stage of the project and that have implications on the LEED® rating criteria. To identify possible relationships between the rating system or environmental assessment tool, the delivery system, and the integration of AEC+P+F, the processes by which stakeholders interact must first be identified.

This research proposes a matrix with associations between LEED® criteria, project lifecycle and stakeholder participation. In addition to the lean principles directly impacted by the adoption of LEED® adoption in buildings, the integration of AEC+P+F opens the possibility for additional benefits. For example, the design and construction project schedule may be compressed due to more opportune decision making. Costs may be also reduced due to expediting material ordering and schedule compression. Additionally, the AEC+P+F integration accompanying LEED® certification can address one of the most important aspects of cost and time reduction, that of underutilization of people (Ramkrishnan et al. 2007). The primary objective is to establish mutual influences of the LEED® rating system with the construction project lifecycle. This research also addresses the involvement, importance and integration of owner, architect, contractor, specialty consultants and facility manager for the completion of any LEED® project.

The early involvement of general contractor, specialty consultants, trade contractors and facility manager in planning and design, and the overlapping of design, construction and facility management practices are ways of improving the project lifecycle process flow. These practices are mainly prescribed by the project delivery system defined and adopted by the owner. To minimize the potential for material or time waste, it is important to understand the processes to deliver green buildings, which demand intense interdisciplinary collaboration during design and careful material, resources and system selection early in the project delivery process. Using conventional delivery methods result in process waste on green projects that reduce levels of sustainability and unnecessarily increase project costs (Klotz et al. 2007). To attain a particular green rating score, project participants are becoming involved earlier in the process; information exchanges take place throughout the project lifecycle; and the results of those frequent exchanges impact the value to the owner. This framework approaches lean thinking, in particular the transformation-flow-value (TFV) theory of production (Koskela 2000), by generating value to the owner, improving flow, and transforming the inputs required for the selection of materials, resources and systems, to outputs in the green rating scale.

AEC+P+F INTEGRATION AND INTEGRATED PROJECT DELIVERY

The traditional construction practice has several characteristics that prevent the improvement of overall performance and sustainability of a project. Some of these include: the supply chain fragmentation; no unified standards for information exchange; poor cross-disciplinary communication with many sub-processes carried out by different professionals who may not be contractually responsible to each other, creating a culture of adversarial roles; overall lack of transparency in processes; and finally a false belief that each project is unique disallowing transfer of knowledge from one project to the other (Sun and Aouad 2000). However, research suggests that 80% of building inputs are repeated (Sun and Aouad 2000). Negative traditional characteristics may cause good ideas to be held back since many subcontractors are brought into the process after the drawings have been completed or are in the design development stage. Furthermore, when bought into the design phase, subcontractors may have little commitment because there are several companies that might bid the project in the future. These subcontractors, hoping to win the project, reserve their ideas and if they do not win the project or if it is too late to incorporate them, the ideas are lost to the

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project. Additional negative practices include contract wording which primarily deals with remedies and penalties, limiting cooperation and innovation from the general contractor and among different subcontractors. It has also been observed that there is an inability to coordinate the work of the different project participants, as well as pressure for local optimization, in which each project participant tries to improve his own performance at the expense of the overall project or other party. Compensation structures based on self performance and lack of transparency also contribute to these negative characteristics (Matthews and Howell 2005, Sun and Aouad 2000, Forcada Matheu 2005).

Currently there are numerous drivers triggering the construction industry to move towards a more integrated approach in order to respond positively to the current sustainability, generational, cultural and market challenges. There is wide international competition, governments are supporting project integration, and there are enormous technological developments (Sun and Aouad 2000). Also, projects are increasing in complexity, owners have greater expectations, performance measurements are now different from the traditional first cost approach (e.g., quality, sustainability, lifecycle cost, completion time), and the market is forcing collaboration. Additionally, owners are requesting more integrated solutions (i.e., resources are very limited therefore there is need to improve productivity and efficiency), and there is desire by all project participants to reduce litigation (Georgia Tech A/E/C Integration Workshop 2007).

In response, the integration of the construction industry is starting to take shape. The American Institute of Architects has developed the concept of Integrated Project Delivery (IPD) (AIA National and AIA California Council 2007) and the ConsensusDOCS Coalition from the construction side has released the ConsensusDOCS 300 Standard Form of Tri-Party Agreement for Collaborative Project Delivery (ConsensusDocs 2008).

IPD is a project delivery approach based on a collaborative process that integrates project participants, business structures, systems and construction practices, in order to connect and boost project participants' talents and insights, optimizing project results, increasing value to the owner and other project participants, reducing waste and raising efficiency throughout the project lifecycle. This approach can be used with different contractual agreement structures and the team includes members beyond the owner, designer and general contractor (AIA California Council and McGraw Hill 2007, AIA National and AIA California Council 2007).

According to AIA National and AIA California Council (2007) the principles of IPD are: first, mutual respect and trust, because the key project participants understand the value of collaboration, working as a team on the best interest of the project; second, mutual benefit and reward, in terms of giving incentives according to achieving project goals; third, collaborative innovation and decision making; fourth, early involvement of key participants; fifth, early goal definition; sixth, intensified planning, investing more time and effort in the first phases of projects and decreasing conflicts during execution; seventh, open communication, defining each member responsibilities, changing the blaming culture from determination of liability to resolution of problems; eighth, appropriate use of technology; and ninth, organization and leadership.

The most important changes that the industry needs to achieve in order to attain integration are the assembly of the project team in a collaborative manner and phasing the project as a flow from conceptualization through implementation and closeout, and moving all design decisions to the early process stages where they are more effective and less costly. In a traditional lifecycle process the project phases are pre-design, schematic design, design development, construction documents, bidding, construction, closeout, and operation. During the five initial phases the project participants define what the project is. In the construction documents phase the stakeholders determine how to develop the project. In the bidding phase the developer of the project is defined, and in the construction phase the actual construction takes place. In the traditional approach the owner and designer are part of the project from pre-design, the project consultants are brought in the schematic design, the general contractor is brought in usually at the construction phase and sometimes before to give some advice, and trade contractors are brought in during the construction phase.

The integrated approach proposes a change in the name of the project phases to conceptualization,

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criteria design, detailed design, implementation documents, final buyout, construction, closeout, and operation. According to this approach the project is defined in the first three phases, project development is determined from the conceptualization stage to the final buyout, the project developer will be selected at the conceptualization phase, and the construction takes place in the construction phase. Within this approach the owner, designer, design consultants and general contractor are brought into the project at the conceptualization stage and the key trade contractors are brought in the design criteria phase, with the trade contractors not key participants until the buyout phase (AIA National and AIA California Council 2007, AIA California Council and McGraw Hill 2007).

IPD can be applied to any project delivery method with the exception of pure Design-Bid-Build. However, certain characteristics of individual project delivery methods will affect the degree of integration attained. Both Construction Management at Risk and Design-Build are better suited for integration, however neither will provide 100% integration if the definition of project team and phasing is not transformed.

METHODOLOGY

This paper proposes a framework to explain the mutual influences between LEED® categories, the lifecycle activities in an integrated project, and the project participants involved in that particular category and activity, through the development of a matrix. A matrix is used because it visually represents the intersections between each project activity and each sustainability category, and shows the team participant that should have a major role at that intersection. The matrix is based on the main phases of the lifecycle of the Integrated Project Delivery approach: conceptualization, criteria design, detailed design, implementation documents, construction, and operation and maintenance, and the six LEED® categories (drawn from LEED® New Construction, version 2.2). On the horizontal axis, the phases of the IPD are expanded to 48 main activities, while on the vertical axis, the LEED® categories are divided by 65 different credits, and prerequisites. The intersecting cells provide a LEED® credit/prerequisite and a project lifecycle activity considered to represent mutual influence between the two components. Therefore, for each LEED® credit/prerequisite/point, 48 possible influences result. The project phases and their respective activities are presented in Table 1. These activities have been defined by the authors taking into consideration the phases and outcomes of each phase stated by AIA National and AIA California Council (2007) on their definition of IPD, in addition to activities that are industry standard, and will be validated in later research.

The intersecting cells are populated with appropriate project team members involved in that specific activity. Although the matrix does not take into consideration all project stakeholders, it includes the main players, O-owner, A-architect, C-general contractor, S-specialty consultant, F-facility manager, and T-trade contractor. The matrix implies that the specified project participants would have an impact not only on the activity, but on the corresponding LEED® credit category. In order to complete the matrix an extensive study of the USGBC LEED® reference guide and of the Impact of LEED® NC Projects on Constructors from Michigan State University (Syal 2007) was carried out, as well as a close review of the AIA guide on Integrated Project Delivery. The matrix was filled out according to the authors' knowledge and experience and will be validated though expert opinion. This is ongoing research and the next step is to conduct interviews with team members who are currently involved in projects that are pursuing LEED® certification and who are starting to use an integrated project approach.

After the matrix is filled out with the project participants who have input and make contributions to the particular credit/prerequisite and activity, the contribution of each stakeholder to each LEED® category at each project phase is calculated as a percentage of the total contribution of all stakeholders to that LEED® category, at that phase. In order to calculate the percentages, the number of times each stakeholder is present in each category and phase are added for each key project participant, and the total number of times all project participants are present in the same category and phase are added as well. These two numbers are used to calculate the percentage for each project participant.

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TABLE 1. Project Phases and Activities.

Conceptualization	• Identify Team • Determine Project Performance Goals • Determine Communication Methodologies • Development of Cost Structure and Preliminary Schedule • Identify Potential Project Risks and Best Team Member to Handle Them • Review of Regulatory Considerations • Define Project Scope • Identify Potential Sites
Criteria Design	• Define Scope • Define Design Options • Determination of Best Option According to True Value Engineering Select Key Trade Contractors • Define Major Building Systems (Structure, skin, MEP) • Agreement on Tolerances between Trades • Accurate Cost Estimate and Schedule
Detailed Design	• Design all Major Systems • Engineer and Coordinate all Building Elements • Finalize Agreement on Tolerances between Trades • Establish Quality Levels • Identify Long Lead Items • Complete Prescriptive Specifications • Detail Cost Estimate and Schedule
Implementation Documents	• Finalize Cost estimate and construction schedule • Finalize Specifications • Shop Drawings from Key Trade Contractors • Starting Prefabrication
Construction	• Contracting of non Key Trade Contractors • Site Preparation for Construction • Prepare Remaining Submittals • Foundation • Sub Structure • Super Structure • Exterior Closure • Develop Interior Space • MEP • Site Development • Inspection & testing as per QC plan • Progress review meetings • Project Monitoring • Construction site Clearance • Ensure Systems meet the owner requirements • Operations & maintenance manual, as builts, and training
Operation and Maintenance	• Post Occupancy Test of systems • Operational Adjustments • Periodic Customer Survey • Periodic Building Assessments • Regular training of O&M personals and new users • Proactive Maintenance of Building systems

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MATRIX DESCRIPTION

A matrix chart is prepared by aligning important project lifecycle phases on the horizontal array, while the vertical array has LEED® categories from the New Construction version 2.2. The project lifecycle activities are based on IPD. Many of these activities closely relate to the traditional project delivery (TPD) approach; however there are some activities intrinsic to the new approach and some that were used in the traditional approach but are moved to a different phase in the IPD. This paper does not intend to explain the 48 activities, just to mention those activities that differ from the TPD. In the conceptualization phase it is necessary to identify the project performance goals and the metrics for project success, to determine the communication methodology, and finally to clearly define the scope of the project. Afterwards on the criteria design phase, many activities that are usually developed later on the project are brought to this phase, therefore the design options are selected, the main systems are defined and the major difference is that the key trade contractors are brought on board very early in the process to help with the systems definition and to start the agreement on tolerances between the trades. For the purpose of LEED® projects, the key trade contractors are mechanical, electrical, plumbing, and structures. Later during the detailed design the building systems are finalized and the building elements are engineered and coordinated, the quality levels are established, the specifications are finalized, and the long lead items are identified. During the implementation documents the construction means and methods are determined, and activities that usually were performed during construction are brought to the design phase, such as the shop drawing process of the key trade contractors and the start of prefabrication. Construction phase activities, including the close out and commissioning process, are very similar to the traditional approach activities. However with the integrated approach the construction process is smoother because the number of Requests for Information (RFIs) and the administrative and coordination effort could be substantially reduced with the previous involvement of the construction team and the increased understanding of the design intent by the entire team. Finally, facility operation and maintenance activities are very similar. However it is expected that users' satisfaction is increased and construction rework is decreased because the facility actually encompassed the requirements of the owner, users and facility management team.

The LEED® categories include Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and Innovation and Design Process. Every credit and prerequisite is evaluated under the proposed matrix. Each cell in the matrix represents the influence of the project phase to LEED® credits or of the LEED® credit to the project phase.

"FOCAST" was chosen as the matrix nomenclature to represent project participants, where F stands for facility manager; O the owner; C-contractor; A-architect; S-specialty consultants; and T-trade contractors. Accordingly, the "FOCAST Matrix" presents each cell filled with the F/O/C/A/S/T letters based on the project participant's involvement to attain a particular LEED® credit and the project stage or task where they make critical sustainable decisions or contributions. The matrix is extremely large to be presented in this paper; however, Figure 1 shows a portion of the matrix to aid in understanding.

RESULTS AND ANALYSIS

The percentage of participation and influence of the different key project participants at each intersection of project phase and LEED® category is presented in Table 2. This participation and influence will be validated in the next phase of research and is a current limitation of this paper, as it is an initial, proposed result.

Conceptualization

During the conceptualization stage, project participants as a team define what the project is and what its goals are, who will be in charge of the different tasks, how the tasks will be executed, and how those tasks will contribute to project success. Analyzing the Sustainable Sites LEED® category during the conceptualization phase, the owner, the architect and the specialty consultants have the major contributions. The participation of the facility manger and the general contractor is important, although in a secondary role. The trade contractors are not part of the team, yet.

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FIGURE 1. Portion of the FOCAST Matrix.

Owner - O, Architect- A, Contractor-C, Consultant- S, Facility Manager-F, Trade Contractors T		PLANNING & DEVELOPMENT PHASE							
FOCAST		Conceptualization							
LEED - AEC Integration		Identify Team	Determine Project Performance Goals	Determine Communication Methodologies	Development of Cost Structure and Pereliminary Schedule	Identify Potential Project Risks and Best Team Member to Handle Them	Review of Regulatory Considerations	Define Project Scope	Identify Potential Sites
	Sustainable Sites								
Prereq 1	**Construction Activity Pollution Prevention**		OSAC	FOCAS	SC	OCAS	OSC	OSAC	OSAC
Credit 1	**Site Selection**		FOCA	FOCAS	OAC	FOCA	OA		OA
Credit 2	**Development Density & Community Connectivity**		FO	FOCAS		FO	OA		OSA
Credit 3	**Brownfield Redevelopment**		FOS	FOCAS	OSAC	FOS	OS		OSA
Credit 4.1	**Alternative Transportation**, Public Transportation Access		FO	FOCAS		FO			OA
Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms		FOA	FOCAS	AC	FOA		OA	OA
Credit 4.3	**Alternative Transportation**, Low-Emitting & Fuel-Efficient Vehicles		OA	FOCAS	OAC	OA		OA	
Credit 4.4	**Alternative Transportation**, Parking Capacity & Car Pool		FOA	FOCAS		FOA		OA	
Credit 5.1	**Site Development,** Protection or Restore Habitat		OSAC	FOCAS	SC	OSAC		OSA	SAC
Credit 5.2	**Site Development,** Maximize Open Space		OSA	FOCAS	SAC	OSA	OS	OSA	SA
Credit 6.1	**Stormwater Design,** Quantity Control		FOSA	FOCAS	SC	FOSA	S	OSA	SA
Credit 6.2	**Stormwater Design,** Quality Control		OSA	FOCAS	SC	OSA	S	OS	SA
Credit 7.1	**Heat Island Effect,** Non-Roof		OSA	FOCAS	SC	OSA		OS	SA
Credit 7.2	**Heat Island Effect,** Roof		OSA	FOCAS	AC	OSA		OA	SA
Credit 8	**Light Pollution Reduction**		OSA	FOCAS	SC	OSA	S	OS	S

The Sustainable Sites category has two main objectives: the first is to locate the project in an appropriate site, and the second is to reduce the negative impacts of the project on that site. The entire team defines the project goals and communication methodologies, evaluates the project risks and evaluates the team member that is best able to handle the various risks. The owner, architect and specialty consultants define, to a larger extent, the scope of work and help on the identification of possible sites. Although the general contractor helps on the scope definition of the prerequisite and one credit, their main involvement lies in the development of cost structure and preliminary schedule.

For the Water Efficiency LEED® category the owner, consultants and architect have the major contribution; however, the role of the facility manager takes more importance. Here the contribution of the general contractor is reduced, and the trade contractors are not part of the team yet. The Water Efficiency category deals primary with the reduction of water consumption and waste water generation, focusing mainly in the landscaping irrigation and the water use within the building. The role of the facility manager is increased by providing the scope definition, different from the participation in the sustainable sites category. The participation of the general contractor is reduced because they are not part of the scope definition in this category.

In the Energy and Atmosphere category the main players are the owner and the specialty consultants. The architect and the facility manager play an important role, and the participation of the general contractor is very similar to the participation in the Water Efficiency category. The trade contractors are not part of the team yet.

The Energy and Atmosphere category main objectives are to reduce the non-renewable energy consumption and optimize the efficiency of the systems installed in the project. The participation of the specialty consultants is higher than in previous categories because they are major players in the scope definition. The architect acts as support for the specialty consultants. The owner gains valuable information from the facility manager, but maintains the role of the major decision maker. The general contractor deals with scheduling and budgeting, but is not heavily involved in the project definition.

Opposite to the Energy and Atmosphere category, in the Materials and Resources category the general contractor plays a major role, along with the owner and the architect. The facility manager and the specialty consultants have a small participation on the conceptualization of this category. The

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TABLE 2. Influence of Project Participants During the Project Lifecycle for Each LEED® Category.

		PLANNING & DEVELOPMENT PHASE	DESIGN PHASE			CONSTRUCTION PHASE	OPERATION & MAINTENANCE
	FOCAST	**Conceptualization**	**Criteria Design**	**Detailed Design**	**Implementation Documents**	**Construction & Commissioning**	**Warranty Period & Life Time Maintenance**
Sustainable Sites	Facility Manager	11%	0%	0%	0%	8%	74%
	Owner	26%	14%	12%	0%	7%	0%
	General Contractor	14%	21%	16%	25%	37%	0%
	Architect	25%	24%	21%	20%	4%	0%
	Specialty Consultant	24%	34%	35%	31%	8%	26%
	Trade Contractor	0%	7%	16%	24%	36%	0%
Water Efficiency	Facility Manager	18%	5%	5%	0%	13%	70%
	Owner	23%	13%	9%	0%	5%	0%
	General Contractor	10%	16%	9%	17%	31%	0%
	Architect	21%	19%	22%	21%	8%	0%
	Specialty Consultant	27%	37%	38%	34%	12%	30%
	Trade Contractor	0%	10%	16%	28%	31%	0%

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TABLE 2. (continued)

		PLANNING & DEVELOPMENT PHASE	DESIGN PHASE			CONSTRUCTION PHASE	OPERATION & MAINTENANCE
	FOCAST	Conceptualization	Criteria Design	Detailed Design	Implementation Documents	Construction & Commissioning	Warranty Period & Life Time Maintenance
Energy & Atmosphere	Facility Manager	14%	6%	4%	0%	16%	67%
	Owner	29%	18%	8%	0%	8%	0%
	General Contractor	11%	18%	12%	25%	26%	0%
	Architect	18%	8%	12%	8%	4%	0%
	Specialty Consultant	27%	39%	41%	36%	22%	33%
	Trade Contractor	0%	11%	23%	31%	25%	0%
Materials & Resources	Facility Manager	8%	1%	1%	0%	7%	100%
	Owner	27%	15%	16%	0%	6%	0%
	General Contractor	29%	35%	30%	33%	39%	0%
	Architect	30%	44%	42%	57%	5%	0%
	Specialty Consultant	6%	2%	4%	0%	0%	0%
	Trade Contractor	0%	4%	7%	10%	44%	0%
Indoor Environmental Quality	Facility Manager	17%	5%	7%	1%	12%	72%
	Owner	23%	13%	10%	1%	7%	0%
	General Contractor	18%	22%	14%	22%	27%	0%
	Architect	22%	29%	26%	28%	8%	0%
	Specialty Consultant	19%	24%	27%	26%	19%	28%
	Trade Contractor	0%	8%	16%	22%	27%	0%

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Materials and Resources category seeks to reduce the use of non-renewable virgin raw materials and the generation of wastes during the construction and operation of the facility. The general contractor, the architect and the owner are the main decision makers and play an important role in project definition and scope of specific credits. The role of the specialty consultant is substantially reduced in this category because the main design professional for materials definition is the architect. The general contractor helps define the materials and plays an important role on materials procurement in terms of availability. The primary input from the facility manager is to provide building requirements for better operation, for instance, in terms of collection of recyclables.

In the Indoor Environmental Quality category all team players involved in the conceptualization phase play a very important role, with the owner and the architect having a slightly larger participation than the rest of the team. The Indoor Environmental Quality category deals with the welfare of the users of the facility and has three main components: one is the design of the systems to provide adequate ventilation and thermal comfort, another to provide clean air to breath, and a final one is to provide users the possibility to control their own environment. The owner and the facility manager have the major requirements from the users, the architect and the general contractor are involved with decisions on materials that may or may not emit contaminants, while the consultants are more involved with the scope of systems (e.g., ventilation, thermal comfort, lighting).

The matrix also includes the sixth category of LEED® Innovation and Design Process. This category is very important during the conceptualization phase since the project team can determine which credits are suitable for exemplary performance or which design or operation characteristics of the facility can contribute to an extraordinary credit. Additionally, when identifying team members it is important to determine who the best person is to be the LEED® administrator. The participation of all project participants is very important in order to achieve the Innovation and Design Process credits, and the share of these contributions is the same for every project participant.

Design

The design phase has three different stages: criteria design, detailed design, and implementation documents. During the criteria design the design options are evaluated and selected, the scope of work is completely defined and the team of key participants is completed with the key trade contractors now being brought on board. The detailed design differs from the traditional design development because the design is completed in this phase and an agreement on tolerances is reached between trade contractors. Finally, during the implementation documents how the project will be constructed is documented, and shop drawings for key trade contractors and prefabrication takes place. Even though the design phase is treated as a single phase for the purpose of this paper, the primary project participants change as the project evolves.

For the Sustainable Sites category the role of the owner changes considerably throughout the design. During criteria design the owner participation is important especially regarding completion of the scope and selection of design options. Afterwards during detailed design, the owner role is mainly in the quality level definition. Finally, during the implementation documents the owner does not have a significant role due to design decisions made earlier in the process. The role of the facility manager is almost negligible during the design phase for the credits of sustainable sites. On the other hand, the participation of the architect, even though it decreases throughout this phase, is important as a support to the specialty consultants for some credits such as site development, storm water design, heat island effect, light pollution reduction, and as lead designer for a few credits. The specialty consultants are responsible for the design of this category. Their role is very important and almost constant throughout design, since they define the systems during the criteria design and design them during the detailed design with help from the trade contractors.

The participation of the trade contractors during the design phase marks a difference from the traditional approach because it helps to completely finalize the design before construction starts, thereby fostering prefabrication as the shop drawings are performed earlier. During the criteria design the trade contractors' participation is minor. However, their

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participation increases through the design phase because during detailed design they finalize the agreement on tolerances between trades and participate in the detailed cost estimate and scheduling process. During the implementation documents, trade contractors help finalize these documents and complete the shop drawings. Finally, the general contractor participation is important during the criteria design, getting involved during the selection, value engineering, cost and schedule estimating processes. Later in the detailed decision, the participation from the general contractor is reduced, mainly centering on the estimating and scheduling processes. However, during the implementation documents the role of the general contractor increases again because in addition to the regular estimating and scheduling processes, the construction means and methods are defined.

For the Water Efficiency category, the project participants' participation behavior is very similar to the Sustainable Sites behavior throughout the design phase. The owner has a larger involvement during the criteria design, but his or her participation is substantially reduced at the end of the implementation documents. The involvement of the specialty consultants is very heavy because they design the landscape, irrigation system, and plumbing system, therefore they participate during scope finalization, definition of systems, and design o the systems. The general contractor has a very similar participation to the sustainable sites category, as well as similar participation for the trade contractors. The participation of the architect is based on supporting the specialty consultants who are designing the systems and in defining the equipment that will be installed within the facility.

The participation of facility management changes compared to the previous category. Even though their participation remains small compared to the other project participants, facility managers are important decision makers on the finalization of scope definition of the systems and in establishing the quality levels expected.

For the Energy and Atmosphere category, the owner has a large involvement during the criteria design phase. The owner participates on the definition and selection of the major systems, and defines some building components before they are engineered, such as green power. The owner's participation decreases during the detailed design phase because at that stage, his or her involvement is limited to establishing the quality levels. Furthermore, the owner's participation during the implementation documents is substantially reduced. The facility manager has a small but important participation especially in regard to verification and measurement of scope finalization and quality standards. At this stage, the role of the architect is small compared to the role of the specialty contractor. This is due to the fact that major systems are designed by specialty consultants.

The participation of the general contractor is very similar to previous categories, dealing especially with design options selection and value engineering, cost estimation and scheduling, and construction means and methods. The input of trade contractors is very important on this category. Even though their participation is marginal during the criteria design, they become major participants during the design of systems, the shop drawing process, and bring to the table a wide range of prefabrication possibilities.

For the Materials and Resources category, the participation of project key participants substantially differs from previous categories. The architect becomes the major decision maker in regard to design, and the general contractor provides important input. During the criteria design phase the owner participates on design option selection. Then during detailed design, the participation from the owner is focused on establishing quality levels, and on the implementation documents this participation becomes minimal. The facility manager has a very small participation in this category, dealing especially with the storage and collection of recyclables prerequisite design as well as other green finish selections. The participation of the specialty consultants and the trade contractors is very small and is directly related to the attainment of credits for reusing structural components. Otherwise, their input is minimal because this category does not include any major systems beyond structural.

In this category, the architect is a very important player on the specification of project materials, while the constructor makes decisions related to materials availability. In addition, this category includes some requirements that are the responsibility of the general contractor such as waste management, and regional materials procurement.

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For the Indoor Environmental Quality category, the owner plays a major role, more than in other categories. This role is more evident during the criteria design and detailed design stages, because this category deals with the comfort and well-being of the final users. Therefore, the owner has a higher involvement on finalizing the scope, selecting the design, and establishing the quality level. The facility manager participates during the criteria design, finalizing the verification of thermal comfort and to some extent during detailed design, establishing quality levels. As credits and prerequisites in this category deal primary with the lighting and the mechanical systems, project massing and materials selection; the specialty consultants and the architect act as lead designers for different credits and prerequisites within this category, and their active participation is comparable throughout the entire design phase.

The participation of the general contractor is greater during the first stage of design, it decreases in the second stage, and then increases again at the end of design. Contrarily, the participation of trade contractors is small during the criteria design but increases as the design progresses. During the criteria stage, the general contractor participates on the scope finalization of the credits related to material selection, on value engineering, and on scheduling and budgeting. During the detailed design, the general contractor has input on establishing quality levels, and maintains similar participation levels as in previous categories during implementation. The participation in this category by trade contractors is very similar to their participation in the Energy and Atmosphere category.

As for the conceptualization stage, the participation of all project participants is important for the Innovation and Design Process category. The lead designer on the first four credits will be directly related to the definition of the credits.

Construction

As the design is finalized and the coordination issues are solved on the detailed design and the implementation documents stage, the construction process is intended to be very straight forward. It requires very little involvement of the architect and specialty consultants to respond to inquiries from the general contractor and trade contractors. For the purpose of this paper the construction phase encompasses the construction of the facility and the closeout and commissioning processes.

In Sustainable Sites category the main players are the general contractor and the trade contractors because they are responsible for performing the actual construction. The major involvement of the owner, facility manager, architect and specialty consultants is in the commissioning process.

The key project participants' involvement in the Water Efficiency category is very similar to the participation on the Sustainable Sites category; however there is a slightly larger involvement by the facility manager, architect and consultants, because there are more systems that should be commissioned.

For the Energy and Atmosphere category the involvement of the owner and architect remains very small and is mainly during the closeout and commissioning process. The role of the general contractor and trade contractors is very important and is related to the actual construction of the facility and the training of the final users on the systems constructed. The participation of consultants and the facility manager is more significant in this category than in the previous categories because most of the systems have to be commissioned and require heavy involvement of the facility manager in the training procedures.

For the Materials and Resources categories the contruction process is highly dominated by the general contractor and trade contractors. The facility manager, the owner and the architect have a minor participation on the closeout process. The specialty consultant does not play a significant role in this category.

The involvement of key project participants on the Indoor Environmental Quality category during the construction phase is very similar to their participation on the Energy and Atmosphere category. Specialty consultants and the facility manager actively participate during the commissioning and training processes, mainly because of the major systems involved in this category.

Operations and Maintenance

The operation and maintenance phases for the IPD and the TPD are very similar. The major differences are expected to be that because of the early involvement of users and the facility manager, the facility

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better serves the final users, and rework is reduced. The matrix includes this phase; however, the result is very similar for most of LEED® categories. The major player in O&M is the facility manager and for most categories he or she will have support from external consultants. Many of these consultants will be different than those involved during the previous phases since contracts beyond construction and installation are for different services. For the Sustainable Sites category, the facility manager and, as needed, the external consultants are involved in minor operational adjustment and periodic facility assessment. The facility manager is involved in regular operation and maintenance training of new personnel and users and in the proactive maintenance of the facility. For the Water Efficiency category the role of the facility manager and external consultant is the same; however, an additional periodic costumer survey should be performed in order to maintain high user satisfaction. This is especially true if technologies such as grey water recirculation, waterless urinals or composting toilets are used for first time. For the Energy and Atmosphere category the facility manager and external consultant involvement is very similar compared to the Sustainable Sites category; however one major difference is the post occupancy test of the energy systems that should be performed by the commissioning consultant with support from the facility manager. For the Materials and Resources category the participation is mainly of the facility manager and is based primary on regular training on operation and maintenance for new personnel because of the new materials involved in the project. It is very beneficial to have a periodic education and feedback from users to improve the storage and collection of recyclables. Finally for the Indoor Environmental Quality category, the facility manager and the external consultant are part of the minor operational adjustments, periodic building assessment, and verification surveys for thermal comfort of the final users. The facility manager should be in charge of periodic customer surveys regarding ventilation, lighting, and thermal comfort to ensure user satisfaction. In addition, the facility manager should perform the regular training of operations and maintenance personnel and perform proactive maintenance of building systems.

RELATIONSHIP BETWEEN AEC+P+F INTEGRATION, GREEN CONSTRUCTION AND LEAN CONSTRUCTION

Lean production principles, such as to make everyone responsible for product quality, to make the process transparent so the state of the system can be seen by anyone from anywhere (Howell and Ballard 1998, Ballard and Koskela 1998), constant flow of information, and avoidance of local optimization that leads to sub-optimal project performance (Matthews and Howell 2005) are shared by the IPD. The integrated approach seeks to incorporate all key stakeholders early in the project as an entire team responsible for the integrated project. Therefore, the goals and risks are evaluated by the team, and the success of each party is tied to the success of the project. The team is responsible for project quality; the knowledge and expertise is shared with the entire team and communication is opened among the stakeholders. The project is not broken into separate phases, but is understood as a continuous flow of information. The integrated project structure allows innovation from the trade contractor level and allows collaboration with different parties in other to improve the performance of the project, instead of improving the performance of single parties sometimes at the expense of the project or other participants. In addition, these lean principles are clearly reflected in the matrix by means of engaging stakeholders in the attainment of LEED® certification from the early stages of conceptualization and design through commissioning and operation. In the classical definition of lean construction (LC), which is to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value (Koskela and Howell 2002), these early interactions in project conceptualization, through design, construction and facility management take place to meet the sustainable rating requirements, and provide the maximum possible amount of value for the client in the quest for the LEED® target level.

To illustrate the lean focus of the LEED®-FOCAST integration, an implementation methodology in the form of "Plan-Do-Check-Act," which is an iterative four-step problem solving process typically used in quality control (Deming 1986), is presented in Figure 2.

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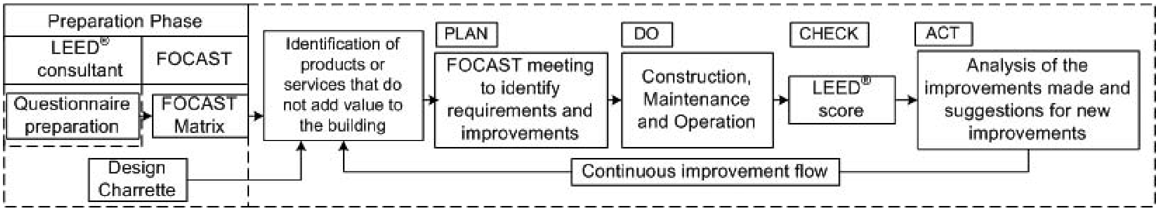
FIGURE 2. LEED®-FOCAST Integration Implementation Methodology (adapted from Robert and Granja 2006).



The LEED-FOCAST integration implementation methodology promotes a situation of continuous improvement of the processes carried out by AEC+P+F project participants. Similar to the PDCA cycle and kaizen costing methodology (Robert and Granja 2006), the LEED®-FOCAST cycle follows a routine of continuous improvement, starting at the planning and development phase through engineering design, construction, and into maintenance and operation. The design charrette process is a focused and collaborative design effort and brainstorming session. The purpose of this process is to promote the exchange of ideas and information, thereby allowing integrated solutions to develop. During initial preparation, the LEED® consultant sets up the FOCAST matrix, filling each cell based on the project participant's involvement to attain a particular LEED® credit and the project stage or task where they make critical sustainable decisions or contributions. The design charrette process, with input from the FOCAST matrix, serves to identify the products or services that do not add value to the building. During construction, maintenance and facility operations, the rating score is determined and checked. Based on an assessment of the FOCAST matrix and the owner requirements specified in the first charrette process, an analysis of the improvements made to the design, construction, maintenance and operation cam be made. Additionally, suggestions for new improvements are gathered from the AEC+P+F project participants involved in the lifecycle stages of the project.

This paper intends to set a base for further research in the quest for increased project stakeholder collaboration with the implementation of LEED® in new construction.

CONCLUSIONS

In order to construct sustainable buildings, current methods of project delivery need to adopt sustainability considerations. Traditional project delivery approaches do not provide the required increase in collaboration among project team members from the early stages, a requirement for truly sustainable building projects. Additional factors that need to be considered and that can aid in successful LEED® certification of buildings include the selection of project team members with LEED® accredited professional designation, increased communication and coordination among team members from the start, or at least earlier in the project, and design options and systems selections based on their environmental impact through value engineering. Additional factors contributing to successful sustainable projects are an early focus on lifecycle value, reduction of construction waste through waste management and other methods of controlling environmental impact, and better indoor environmental quality achieved by reducing the exposure of construction materials in the atmosphere during construction.

With the potential to maximize attainable credits, the integrated project delivery approach could be very suitable for a LEED® project, with its early contribution of key project participants in a collaborative, open communication relationship. As presented in the matrix and the table, in order to optimize the LEED® credits and prerequisites, decision making should be placed early in the conceptualization and criteria design phases of the project; therefore, early contribution by all team members is required. Each key stakeholder plays a different role within the project as the project evolves, and the intention of the integrated approach is to maximize these roles.

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At the beginning of the project the participation of the owner and facility manager is essential to define the project according to the users' needs and requirements, and then during the early design stage the participation of the architect and the consultants takes more importance because they define the design options on different levels. During the late design the participation of trade contractors helps finalize the design and coordinate the construction processes. During the construction process the general contractor and all trade contractors make the major contribution to the project, and finally during operation and maintenance the most important player is the facility manager; however these leading project participants at each phase are substantially supported by other team members.

Most key stakeholders are involved in the conceptualization phase so that everyone understands the project goals and objectives. Similarly, the entire team is engaged at the criteria design phase with the inclusion of key trade contractors, giving all team members the possibility of fully utilizing their specialized capabilities to benefit the project. Finally, each project team member should be able to contribute to the initial group meeting process, also referred to as a charrette, where each member investigates and shares opportunities for the addition of LEED® credit points. The charrette also provides members the opportunity to approve and to assess the attainability of each recommendation.

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