LEAN PRINCIPLES TO INJECT OPERATIONS KNOWLEDGE INTO DESIGN

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ABSTRACT

Buildings represent a significant financial investment to owners, which is often carried for many years. Just as Toyota realized that the car assembly line accounted for only 15% of the total manufacturing process, the design and construction of a building amounts to only 20% of the total cost of a facility over its life-cycle. Importantly, research has shown that when just one percent of a project's up-front costs are spent, up to 70% of its life-cycle costs may already be committed. More research is needed to bridge the information divide between the development and operation of a facility.

Progressive tools and strategies such as Design-Build-Operate-Maintain (DBOM), Design for Maintainability (DFM), and Concurrent Engineering have been developed to assist the design team in their focus on operations and maintenance (O&M) issues. Yet obstructions to the use of O&M knowledge in design still remain. It is argued that this is because the information flow of O&M knowledge into project design is poorly understood. This paper develops a model for exchanging information between design teams and O&M using the principles and tools of lean production to be implemented as a case study. To achieve an O&M compatible design, O&M information ideally ought to be received by the design team in a just-in-time fashion. This paper first explores the obstructions to O&M knowledge transfer, and then proposes a kanban system to facilitate the exchange of information. The paper discusses the triggers and media for the pull of O&M information into building design, as well as the types of projects that would be most receptive to this strategy.

KEY WORDS

Sustainable Construction, Operations and Maintenance, Design for Maintenance, Design Process, Design Intent Document

INTRODUCTION

For project teams in the construction industry, the life of a project lasts at most a few years. A design team defines the facility for the construction team, and the operations team inherits a completed facility. After building turnover, the operations team is engaged to operate and maintain the plethora of customized building systems.

The Architecture, Engineering and Construction (AEC) industry is adept in the formation of project teams for the project development phase of a facility, but not as capable at integrating expertise from the operations phase. In the U.S., the increasing use of sustainable buildings to meet owner needs is making this weakness particularly acute. Owners are increasingly asking for sustainable facilities, in large part due to the Leadership in Energy and Environmental Design (LEED®) rating system developed by the United States Green Building Council. Long term owners, those that will own and occupy their building for a significant period of time, have the most to gain in addressing this weakness as sustainable facilities are healthier for occupants and have reduced annual energy costs.

Sustainable construction strives to reduce the environmental impact of buildings through

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reduced energy consumption, efficient use of resources, and improved indoor environmental quality. To accomplish this, project teams must look beyond building turnover, into the building's operations and maintenance (O&M) phase. Seemingly minor design decisions made early in the project can have a significant impact on the O&M procedures and requirements.

An example of this lies in the design of a mechanical system. Fan Powered Induction Units (FPIUs) allow for greater occupant comfort and control as well as a more efficient system. However, each individual unit has heating and cooling coils requiring maintenance access points at each unit, very different from a centralized mechanical system. Addressed at the system level of design, these issues can be incorporated in the design early. Proper communication between the design team and O&M team allow for optimal orientation and placement of access panels to help ease the maintenance burden.

To improve this process, Toyota's set-based design provides a foundation for this paper to examine a strategy that will help to generate and communicate potential problems. Toyota's set-based design provides a foundation for a strategy that will help to generate and communicate potential problems importance on decisions made at the systems level of design (Sobek & Ward, 1996). Tools and strategies (e.g. Design-Build-Operate-Maintain and Design for Maintainability) exist to bring O&M into design, but communication is essential to make an improvement. A feedback system within the design process facilitates the injection of O&M into the design, enabling communication between two previously isolated teams. The Design Intent Documents are proposed to be used as the signal cards for a kanban system, soliciting feedback when the system is defined in further detail.

BACKGROUND

THE VALUE OF O&M

Operations and maintenance staff provide essential value to obtaining the sustainable goals of buildings. However, tasks to reach sustainable goals are often not seen as important as their primary roles of maintenance, repair, custodial and landscape services. An example of this lies in the cleaning solutions used throughout the building; a solution that performs better may not be environmentally-friendly and will likely be used in place of environmentally safer solutions, sacrificing sustainable objectives.

O&M activities that overlap sustainable goals and their primary role are of critical importance to a high performance building. An example of this is the regular cleaning and replacement of filters in equipment that is essential to maintain system efficiency and a healthy indoor environmental quality. In general, improper O&M can lead to increased energy consumption, reduced occupant comfort and premature failure of system components. When this occurs, neither equipment needs nor sustainable goals are met.

Proper training and education for the facilities O&M staff is critical to ensure all system requirements are communicated from the system designers and installers to the system operators and maintainers. Training is usually included in the commissioning of a building, but must be addressed thoroughly, and presented in a way that can be used to educate new employees in the event of staff turnover, reorganization or promotion. Equipment manuals, parts lists and vendors are key components of the commissioning documents, but they do not illustrate the interdependency of all systems within the building. By educating O&M staff to understand their building's systems in a greater level of detail, the project team better prepares them in the event of system malfunction. Problems can be addressed faster and more accurately, reducing the negative impact on the building's environment.

The traditional project delivery methods hinder the development of a relationship between the design team, the construction team and the O&M team. Duggan and Blayden (2001) describe this as an insufficient allowance being made for "building an appropriate level of organizational capability and support infrastructure to enable the [facility] to perform effectively at start-up." While the facility is turned over in good condition, it quickly degenerates "due to the way people work together coupled with a lack of knowledge and expertise in the operating organization and an absence of effective engineering change control procedures." Proper training and preparation of O&M staff through their involvement in the design and construction would help to prevent this situation.

The AEC industry has not fully embraced the value that O&M personnel can contribute to the design of building systems. By injecting O&M knowledge into the early phases of the project design, value can be added through an increased efficiency of building O&M for the lifetime of the building. However, tensions exist that must be balanced to ensure design decisions are not made prematurely, limiting the true potential of the design; or too late, delaying the process. An example of this would be deciding to use a variable air volume (VAV) mechanical system, when decisions later in a project prefer a constant

volume (CV) system. In addition, O&M involvement in system design must be in a *just-in-time* fashion to ensure no waste is added to the design process.

To increase the O&M role in the project delivery process, organizational tools and strategies can be implemented such as Design for Maintainability (DFM) and Design-Build-Operate-Maintain (DBOM). DFM is a design strategy focusing on the reliability and ease of maintenance of systems. DBOM is a project delivery process that includes the architect, engineers, contractor and operations and maintenance provider under one contract to the owner. Both have a strong potential for increasing maintainability, as well as sustainability.

COMMITMENT OF COSTS

Operations and maintenance (O&M) costs represent the greatest expenditures to an owner over the life of a building, typically amounting to six times that of the initial expense (U.S. Federal Facilities Council, 2001). However, the magnitude of O&M costs is determined very early in the design (see Fig. 1); therefore, high quality, timely O&M information is needed. For instance, Romm (1994) argued that when just one percent of a project's up-front costs are spent, up to 70 percent of its LCC may already be fixed. To be effective, O&M staff must provide input in the early phases of design to see substantial reductions in annual operating costs.

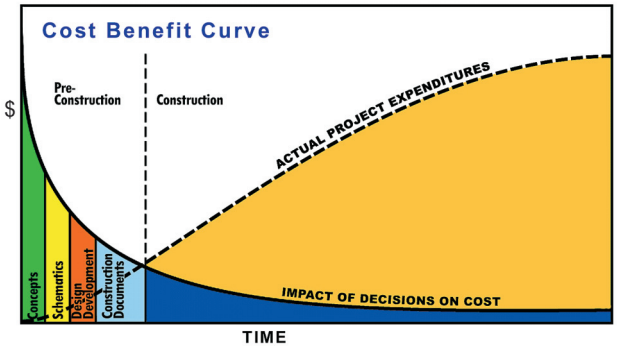

Figure 1: Level of Influence on Cost as Compared to Time. (After Paulson 1976).

METHODS TO IMPROVE O&M SUSTAINABILITY

PROJECT DELIVERY

Design-Build-Operate-Maintain (DBOM) is a project delivery system that contracts the design, construction, operations and maintenance functions for the facility as one entity to the owner. The contractor, usually a joint venture between a design-build firm and an operations firm, holds a single contract with the owner. The term for the O&M of the facility is typically 10-15 years. By introducing O&M teams to the design teams and contractors early in the project, the first cost knowledge base of the designers and contractors is complemented with a post-construction knowledge base of the O&M team. It is critical to involve the individuals who will be directly responsible for upkeep of the facility on a daily basis.

The DBOM contract period is lengthier than Design-Bid-Build and Design-Build contracts due to the inclusion of O&M. This creates opportunities for project teams when designing value (Dahl et al, 2005). Life-cycle cost analysis (LCCA) can contribute directly to the profitability of project teams. By evaluating design options and comparing initial costs as well as long-term costs, teams have the opportunity to select a system that reduces annual operating costs, boosting the profitability of projects. Not only do project teams benefit, but owners benefit by reducing lifetime operating costs for the facility. A reduction in energy use may be the underlying factor in reducing the operating costs, allowing the owner to achieve sustainable goals.

DBOM allows relationships to be built and an infrastructure generated to assist in providing seamless turn-over from construction to operation of the facility. However, the organizational structure of the project team does not guarantee success. For this, a communication system, one that indicates when O&M knowledge needs to be considered in the design, is required.

DESIGN FOR MAINTAINABILITY

Design for Maintainability (DFM) is a design strategy that seeks to increase facility reliability and ease the maintenance requirements of building systems. Duggan and Blayden (2001) assert the usual process of equipment design and selection as being "carried out with insufficient input from the operations and maintenance perspective." This can lead to compromising sustainable goals for the project, and even worse, the specification of a system that has inherent faults for the installed application.

In the application of DFM, a maintainability champion increases the depth of knowledge of the project team, and keeps efficient building O&M as a primary concern in the project. The champion, being involved in the project from early stages, allows value to flow into the design process in a *just-in-time* fashion. Table 1 summarizes some of the primary concerns of the maintainability champion.

Table 1: Critical Concerns for Maintainability in Design (Adapted from Mostia, 2001)

Critical Concerns for Maintainability in Design	
Keep Systems Simple	Standardize Components
Employ Modular Design	Document Systems
Preserve Accessibility	Label Consistently
Streamline Testing	Prevent Maintenance
Simplify Troubleshooting	Predict Maintenance
Accommodate Safety for Maintenance Personnel	
Provide Resources Necessary for Repair	

Duggan and Blayden (2001) suggest the use of an Operation Capability Development (OCD) team to be the link between the design team/construction management project team and the owner's team of O&M. The level of involvement for the OCD team is not specifically defined, besides the emphasis on early involvement and having an agreed plan in place. However, to ensure that the addition of resources like the OCD are not also adding process waste to design, the interactions between maintainability champions and the design team must be undertaken at the right time and at the right level of detail.

KNOWLEDGE MANAGEMENT

Receiving accurate information at the right time will allow design teams to make the right decisions the first time. Value is improved and waste is reduced. Using Design Intent Documents (DIDs) can ensure the maintainability input is received in a *just-in-time* fashion. DIDs are developed throughout projects to characterize the objective and performance of building systems. Although a component of the commissioning process, the creation of the DID begins with the owner. The DID communicates the value of a system from the owner's perspective.

As the project progresses, the DID is refined and developed into an increasing level of detail. This can represent a powerful tool to someone unfamiliar with the project (e.g. maintenance personnel hired after the building has been in service for five years), but also must be created with that intention in mind (Ellis, Aug 2004). This creates an ideal opportunity for the injection of O&M knowledge into the design process. The DID allows future O&M personnel to understand the needs and capabilities of the system prior to changing the configuration, making upgrades, or performing repairs (Duggan and Blayden, 2001), but it also allows the O&M team to evaluate the maintainability of systems prior to operation.

THE RELATIONSHIP TO LEAN PRINCIPLES

Upon completion of construction, building turnover represents a major interface between two groups that has high potential for improvement. Simplified, the groups are the designers and the operators. To approach the situation from a lean perspective, the five lean principles are (from Womack & Jones, 1996):

- Define Value: What does the owner want the building's systems to accomplish?
- Define the Value Stream: How is the design created? More specifically, what is the level of involvement of O&M in design?
- Allow Value to Flow: Eliminate (and do not add) wasteful activities to the design process.
- Pull Value: Allow the designer to *pull* knowledge from O&M at the right time.
- Pursue Perfection: Refine the process by keeping activities transparent.

Combining the efforts of DFM, involving O&M personnel early in the design process, and managing the additional knowledge brought to project teams using DIDs, we approach a product development process.

Using the DIDs to define value and set parameters for achieving project goals, the DID itself becomes a signal card in a *kanban* system. When the DID changes as the project design evolves, the new draft should trigger a review by the maintainability champion or O&M team. Using this system from the commencement of projects allows for design teams to *pull* O&M knowledge in a *just-in-time* fashion.

Using the example of the mechanical system design, the primary version of the DID states the performance specifications of the mechanical system. As the design team evaluates specific types of systems, the DID evolves and becomes a record for the intent of each design decision. Developed with the O&M team, each subsequent draft of the DID communicates the status of the design and allow for a greater transparency of the design process, with little extra effort on behalf of the design team. Input is solicited from the O&M team, with the DID representing an agenda with speaking points for each detail of the system. The mechanical system selection process is discussed, laying out the differences in O&M requirements between FPIUs and a centralized system. Upon selection of a system, further detail is revealed in the DIDs to include equipment orientation and access points, allowing further discussion as to the maintenance requirements of the system.

Value is enhanced using DIDs in a *kanban* system by accounting for LCC specifically in relation to O&M, an aspect which may be unfa-

miliar to design teams. The value stream of the design process is maintained, and the risk of adding process waste is mitigated through consultations with O&M only when the DID undergoes revision. As designers are the 'holder' of the signal card, it is their duty to recognize a change to the DID and *pull* O&M knowledge at the appropriate time. Open communication in healthy project teams allow the process to be refined to pursue perfection.

Comparing this to filters generated by Magent, Riley & Horman (2004) to evaluate key design activities in a Building Design Process Model for High Performance Buildings ($BDPM^{HP}$), it meets many of the requirements. The DID *kanban* system represents an activity that assists in:

- Maximizing value while minimizing waste;
- Defining project specific design goals and objectives;
- Minimizing the chance of losing value during the evolution of system design;
- Actively involving downstream stakeholders (O&M) in design decisions;
- Ensuring all stakeholders are aware of system opportunities and decisions.

CASE STUDY: USING THE DESIGN INTENT DOCUMENT TO INJECT O&M INTO DESIGN

The authors propose the implementation of the DID *kanban* system to inject O&M considerations into the design of a project. As discussed, owners most interested in increasing the focus of design on efficient O&M would be government agencies and owner-occupied buildings. This allows the owner to reap the benefits of a more integrated design process.

A project implementing DBOM would be ideal for this case study, as the O&M team and the design team would both be working towards the same goal. However, projects using delivery systems other than DBOM are expected to see O&M requirements eased as well. A major barrier for studying a project using a Design-Bid-Build or Design-Build structure would be the source of O&M information. Government agencies, such as the Pentagon Renovation and Construction Program Office (PENREN), have O&M staff available for design reviews, but many private companies may not. An experienced O&M staff is of utmost importance for a successful case study analysis.

Performance specifications are another requirement for the project implementing the DID *kanban* system, which allow the design team and the O&M team the flexibility to select the best system for the situation. The use of Quality Function Deployment and the Design Structure Matrix may also help to explicitly communicate the owner's definition of value.

The impacts of using the DID *kanban* system to inject O&M into design will be measured using the Continuous Value Enhancement Process (CVEP). The structure of CVEP is designed to provide a systematic and comprehensive method to evaluate detailed project decisions while collecting building solutions that have the potential to improve project performance (Pulaski, 2005). This will focus discussions around issues concerning maintainability, sustainability and constructability, among others. The maintainability of the system in question will be quantified by the project team through rating the system as compared to alternate systems, much like a House of Quality, using the critical concerns for maintainability outlined in this paper.

Through observing and recording the use of the DID as a tool for communication between the design team and the O&M team, the *kanban* system can be further refined to meet the needs of a high performing project team.

CONCLUSIONS

There is a major opportunity in the AEC industry to enhance the service provided to owners; through increasing the quality of the communications between the project team and the facility's operators. Through active O&M participation in design, decisions will be made knowing the long-term impact on operating costs and maintenance burdens for the facility. The importance of O&M involvement in design is emphasized when using sustainable design and construction. Only through efficient O&M will the facility achieve the owner's sustainable goals.

Contracting structures and design strategies help to keep O&M as a consideration in design, but without O&M involved in the design decisions, any and all assumptions made for LCCAs are inaccurate, resulting in ineffective design decisions. The new information, solicited from O&M (a value stream), can be managed with a *kanban* system. Using DIDs in the form of a *kanban* system ensures the value stream remains intact while communicating design status to project stakeholders.

A case study will help to evaluate the DID *kanban* system and determine improvements necessary to ensure it is a viable tool for injecting O&M considerations into project designs. As a result of injecting O&M into the design process, buildings will be easier to operate and maintain, with reduced energy use and increased occupant comfort in a sustainable environment.

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