Synergies between Sustainable Design and Constructability at the Pentagon

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Abstract

Sustainable design and constructability are two keys for efficient design and construction that are often addressed separately from each other in projects. This paper examines the integration of these two initiatives on the Pentagon renovation. The examination exposes a synergistic relationship between sustainable design and constructability. This relationship strives to efficiently utilize resources and reduce waste in the project. The integrated organizational structure and design-build performance based contracting strategies at the Pentagon have assisted in the implementation of sustainable design and constructability. Connections between the two initiatives were found at the conceptual level, system level, materials level and in the design implementation process. Importantly, the analysis of the Pentagon reveals that the potential to improve the sustainability and the constructability of a project is enhanced when the two initiatives are integrated and approached in a combined fashion.

Introduction

Sustainable design and constructability are both concepts concerned with the efficient use of resources in projects although they are usually addressed separately. The demand for sustainable buildings has grown dramatically in recent years. Typically, sustainable design is associated with a first cost premium because of the higher priced (recycled) materials and more expensive, but more efficient energy saving technologies. These costs are often offset by significant operational and energy savings over the life of the project. Constructability can also achieve notable savings for a project during the construction phase. Russell et al. (1992) showed that improving constructability on a project achieved 12% savings. If sustainable design and constructability can be addressed integrally then savings might be achieved that are not otherwise viable making sustainable design much more affordable.

The Pentagon is the world's largest office building covering 29 acres of land and contains over 6.6 million square feet of floor space. There are more than 17.5 miles of corridors and 7,754 windows. The building has its own heating and refrigeration plant, water and sewage facilities, police force, fire station, heliport, childcare center, cafeterias, mini-mall, Metro station, and medical clinic. With a daily population approaching 25,000 people, it is larger than 9 out of 10 American towns, and it is more complex than many small cities. It is the nerve center of the national military establishment. After almost 60 years of operation, the building was in dire need of a thorough renovation. In 1997, demolition and construction began on the first wedge of the renovation project. The wedge was nearly complete and ready for owner turnover during the 2nd week of October 2001. While the September 11th terrorist attacks destroyed a nation's sense of security, it also demolished the first wedge of the Pentagon renovation project. One year later, the damaged area of the building was completely rebuilt. Meanwhile, the renovation of the remaining portion of the Pentagon (Wedges 2-5) began demolition and reconstruction.

This paper explores the synergies between constructability and sustainable design practices. The organizational structure of the Pentagon Renovation program is explained to show how it has assisted in the collaboration of sustainability and constructability. Explicit connections are drawn between the sustainability and constructability efforts on the projects to show how synergistic these efforts are. It is concluded that sustainable design concepts and constructability principles have some unique and very useful connections that have the potential to be extremely effective in creating buildings that are more efficient, more sustainable and also, easier to construct.

Organizational Structure and Contracting Strategies of the Pentagon Renovation Program

The establishment of the Integrated Sustainable Design and Constructability Team has created a central focal point in the organization serving as an ongoing source of information and guidance to all Pentagon Renovation projects. The organizational structure and contracting strategies were a key factor that encouraged project teams to discover alternative systems and materials that were both sustainable in nature and easily constructed.

Formation of the Integrated Sustainable Design and Constructability Team

The Federal Government has been the leader in the implementation of environmental protection and sustainable design in the building industry. New laws and executive orders such as Executive Order 13123 "Greening the Government" now mandate the behavior of federal organizations. At the Pentagon, the Office of the Secretary of Defense (OSD) is responsible for implementing these Executive Orders and regulations. Two organizations, the Federal Facilities Division (FFD) of Washington Headquarters Services, and the Pentagon Renovation Program work in concert to accomplish these "green" goals. FFD maintains the day to day operation of the Pentagon. The Pentagon Renovation Office (PenRen) serves as the OSD construction agent for renovations and new construction on the Pentagon Reservation property. In both FFD and PenRen, sustainable design and environmentally friendly programs have evolved since 1993 when the Pentagon Environmental Management Committee was created to advise FFD on environmental issues. FFD has required sustainable practices in their maintenance contracts and is constantly incorporating new sustainable, environmentally-friendly practices in their operations of the Pentagon. Since its inception in 1991, PenRen has gradually incorporated aspects of sustainable design into the new construction and renovation. These efforts, although progressive, were hampered by the lack of focus as many sustainable issues were being addressed across multiple projects. No strategic planning for the total Renovation program was in place.

In October of 2000, Dr. Teresa Pohlman joined the PenRen team and soon observed the lack of a centralized focal point for all sustainable activities. In August of 2001 she formed the

Sustainable Design Team to be an ongoing source of information and guidance to all PenRen projects.

Concurrent to this process, a Pennsylvania State University research team conducted a constructability study on Wedge 1 of the Pentagon Renovation. The highly repetitive nature of the project made constructability a high priority. The study found that constructability issues were being addressed, but were being resolved too late in process to make an impact, resulting in a loss of potential savings between $5 – $10 million (Horman & Pulaski 2001).

As the sustainability and constructability efforts progressed in parallel, many examples of common goals and objectives began to surface. The PenRen management recognized the intuitive connection between sustainable design and constructability and in August of 2001, the two initiatives were integrated into one team, the Integrated Sustainable Design and Constructability (ISDC) Team. The complex nature of the projects implemented by the Pentagon Renovation Program requires that the ISDC Team incorporate sustainable design and constructability into the overall acquisition and management strategy of the Pentagon Renovation Program.

A Facilitative Organizational Structure and Supportive Contracting Strategies

The organizational structure of the Pentagon Renovation Program is organized as a matrix format into Integrated Product Teams (IPTs), an approach that was previously used by the Department of Defense in the weapons industry to optimize the completion of complex processes. There are two types of IPTs used: geographic and functional. The ISDC Team is overseen by a functional IPT. The IPT organizational structure creates a wholly integrated management structure that forces integration across disciplines, encouraging communication between project team members.

The contracting strategy and delivery process utilized by the Pentagon Renovation Program eliminates many contractual barriers that often inhibit innovation among designers and contractors and promotes the type of behavior and performance that leads to highly efficient facilities that are completed within project budget and schedule.

Design-build delivery – encourages cross discipline interaction between designers and contractors from the beginning of design. The expertise from a variety of sources can be utilized to develop multiple alternatives while practically knowing what the real costs for construction are. The process supports the integration of building systems and encourages design disciplines to work together with contractors to determine the most efficient, practical and sustainable design solution.

Performance based contracting – and performance specifications were developed to support the design-build delivery process. As an example, for the Wedge 2-5 contract, 3,500 pages of design and specification sheets were reduced to 16 pages of performance specifications (arranged in a simple matrix format) in a 109 page Request For Proposal (RFP). The performance specification provided the design team with the flexibility to search for alternative systems, materials and products that were both sustainable and easily constructed.

Fixed-price, award-fee contracts – with no profit built in allow contractors to be awarded a profit of up to 10 percent of the contract price. One evaluation factor for the award fee determination is “sustainable design”, which encourages the design and construction team to search for innovative sustainable solutions that can be incorporated within the project budget. Shared savings and split overrun clauses are also used to provide additional incentives.

The U.S. Green Building Council’s LEED™ rating system – was used to drive the program’s sustainable design initiatives. It provides a method to influence design decisions and measure the success of implementation across projects. While contractors will naturally choose constructability as a driver for the majority of decisions, LEED™ puts the emphasis back on sustainability and balances the two, allowing the team to arrive at a decision that adequately addresses sustainable design and constructability considerations.

The Integrated Product Team organizational structure compliments the use of the design-build delivery system, provides the necessary framework to encourage the integration of disciplines, projects and personnel. Contractual incentives and the LEED rating system provide the motivation for project teams to design facilities and construct buildings in an efficient, practical and sustainable manner.

Synergies and Connections between Sustainable Design and Constructability

Sustainable design and constructability concepts strive for the efficient use of resources through the reduction of waste. Sustainable design promotes the use of rapidly renewable resources and the efficient use of resources over the life of a project. Sustainability concepts strive to reduce wasted energy, water, and materials in the construction and operation of a facility. Constructability, on the other hand, focuses on waste in terms of the efficient use of materials and personnel by finding easier ways to undertake construction. While constructability concepts are typically implemented to ease the construction phase, they also influence the design and the operability of the facility. Thus, it is argued that sustainability and constructability share a common theme. This section develops this theme and looks at where the synergies and connections exist.

Sustainable design and constructability each have a set of core concepts that help guide projects to reach their respective goals. Table 1 lists five specific guidelines in constructability and sustainability and related common objectives.

Table 1: Common Conceptual Themes between Sustainability and Constructability
(Developed from: CII (1993), Zeigler (2002), and High Performance Building Guidelines (1999))

Constructability Concepts and Guidelines	Sustainable Design Principles and Guidelines	Common Objective
1. Use performance specifications	Use environmental performance based contracting	Focus on performance characteristics that encourage innovation
2. Straightforward designs; avoid unnecessary complexity	Optimize use of universal sizing (standardize rooms/ workstation sizing, use modules of material sizes)	Standardize designs to maximize advantages of repeatable construction; "Back to Basics"
3. Design concepts should be consistent with those generally specified within the geographical region of interest.	Where practical specify and use locally harvested, mined and manufactured materials and products	Consider local and environmental conditions in design decisions and product selection
4. Design for Construction efficiency	Recognize the least costly, least time consuming and most environmentally preferable design	Product design should account for production means and efficiency
5. Specify the most efficient system/material to achieve a given purpose	Optimize the use of engineered materials (i.e. trusses and composite materials). Maximize the use of re-usable, renewable, sustainably managed, bio-based materials	Use systems that minimize field fabrication and associated inefficiencies in labor and materials

The synergy between sustainable design and constructability significantly influences the conduct of the project. An example of this is the "back to basics" focus that became the first motto for Wedge 2-5 project team. Project designs, schedules and contracts had become quite complex due, in part, to the sustainability effort. As a result, management decided to simplify and standardize as much as possible. This desire was also a result of lessons learned on the renovation of the first wedge of the building, where the design and construction process was quite inefficient. The design for the Wedges 2-5 project was simplified to a concept that could be standardized throughout the entire Pentagon. The result was the development of a Universal Space Plan, which breaks down the building into repetitive (approx.) 10,000 sq. ft. sections that serve as one common universal office area. The Universal Space Plan allowed for design optimization and standardization of many of the components and systems in the space including fan powered induction units, smart wall design, and systems furniture. A detailed short interval construction schedule also allowed the contractors to optimize the construction sequencing and coordination in the space to allow for greater constructability.

Synergies and connections exist between sustainable design and constructability in the conceptual, design, system, and material areas of a project. The Pentagon's Universal Space Plan is a conceptual connection. The design and systems integration areas also have notable connections that impact the project. The following sections use specific examples from the Pentagon Renovation to highlight different levels of synergies and connections between sustainable design and constructability.

Design Implementation Process

Best value is obtained from both sustainable design and constructability when these concepts are introduced early in the building process. The early involvement of the mechanical contractor in the Wedge 2-5 Pentagon renovation encouraged the proper integration of different systems. This enabled the different disciplines to coordinate with each other utilizing their respective skills to develop a mechanical system that was less expensive and easier to install due to smaller equipment and less duct work. The mechanical system also improved the indoor environment by allowing additional daylight to enter into the space via a smaller ceiling plenum.

The Pentagon Renovation Program developed better design solutions when they implemented the U.S. Green Building Council's LEED^{TM} rating system earlier in the project. Figure 1 identifies when in the design phase LEED^{TM} was introduced to each project and the LEED^{TM} points obtained from four of the Pentagon Renovation projects. The projects that addressed sustainability earlier in the process spent less money on the initiative and obtained higher ratings. While clearly the later projects reaped the benefits of experience in the earlier projects, earlier timing was an important part of the results achieved.

Timing is also very important to constructability initiatives. Penn State's constructability study of Wedge 1 of the Pentagon Renovation indicated that some decisions were being addressed late in the process resulting in the loss of potential savings between \$5 -\$10 million (Horman & Pulaski 2001). For example the mechanical exhaust shafts where designed to have a uniform duct size rather than transitioning sizes. This change, discovered during construction, eased the fabrication and installation error and provided enhanced flexibility for future additions resulting in an estimated savings of \$780,000. This finding seems to be consistent with the results of other research by the Construction Industry Institute that has shown that early involvement is needed for the effective introduction of constructability concepts (CII 1993).

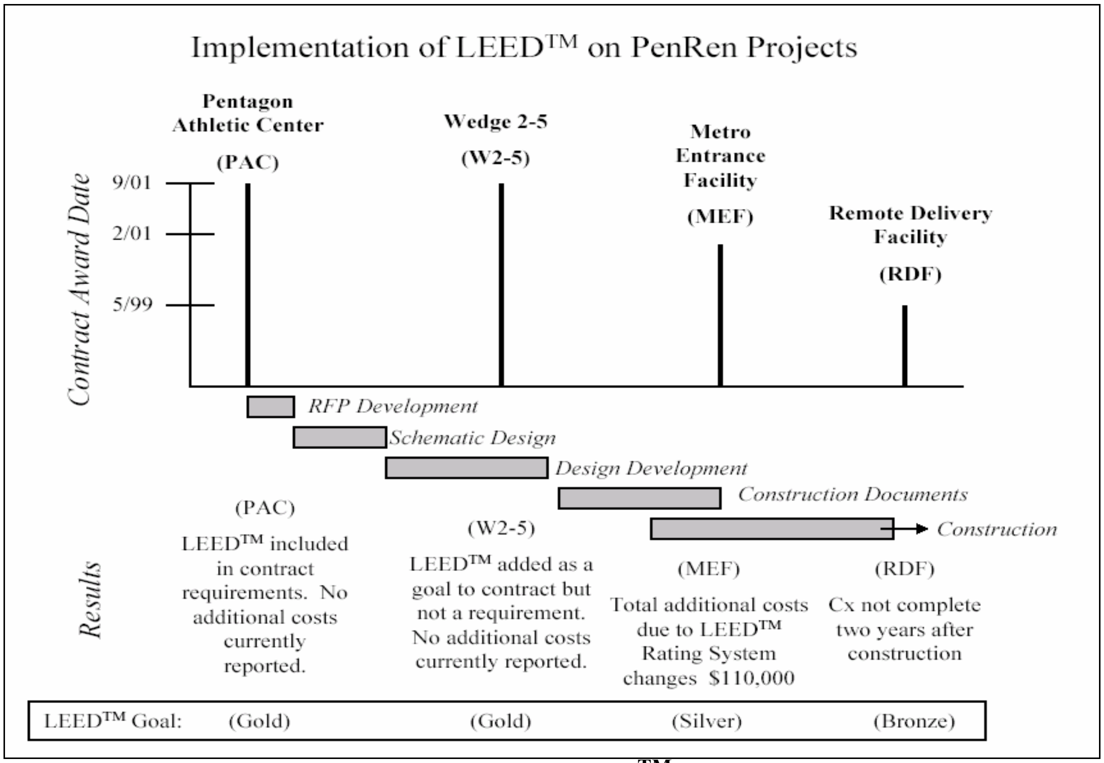

Figure 1: Implementation of LEED™ on PenRen Projects

Systems Integration

The treatment of a built facility as an integrated whole is a key tenant to both sustainable design and constructability. Decisions made concerning the input of constructability often have an effect on more than one design discipline or subcontractor. For example, many constructability improvements come from the interfaces between different materials and different systems. Understanding the different tolerance requirements of a steel frame and glass panel will enhance the installation of the glazed curtain wall system. In the same manner, sustainable design principles and the whole building design approach are very concerned with how different disciplines are affected by design decisions. The “whole building” approach to design and construction results in buildings that use a fraction of the energy of similar buildings without compromising comfort or aesthetics. (Torcellini 2001).

An integrated system approach enhances both sustainable design and constructability. At the Pentagon, the mechanical contractor designed a Fan Powered Induction Unit (FPIU) system to eliminate the use of return air ducts. This allowed for the units to be placed in bulkheads in the middle of the space, leaving the outside portions of the space at a higher ceiling height (23 inches higher than Wedge 1). This significantly improved the penetration of daylight. The FPIU reduced the number of mechanical rooms from 118 in Wedge 1 to only 9 in all of Wedge 2, increasing the amount of available tenant space. The system also reduced the amount of ductwork required, by allowing the return air to be taken directly from the occupied space. This reduced not only the installation cost to the mechanical contractor but opened up the plenum space for the distribution of electrical, plumbing, fire protection and telecommunication systems. On a renovation project, these are substantial construction advantages.

The early involvement of the mechanical contractor allowed for the proper integration of different systems, allowing the different disciplines to utilize their respective expertise to develop a system that was less expensive, easier to install, and improved the indoor environment.

Material Connections

The search for and development of more sustainable products is leading organizations, institutions and companies to more economic products and more efficient methods of installation. For example, extensive research has been implemented in the carpet industry in an attempt to eliminate the use of PVC fibers as well Volatile Organic Compounds (VOC's) in the carpet backing. One carpet manufacturer has developed a spray on adhesive that not only has eliminated the use of VOC's, but is also easier to install. By using a spray on method the manufacture was able to reduce the volume of adhesive used on the project and also provide a system that allows carpet tiles to be easily replaced.

Other new product developments have led to similar installation efficiencies on other projects. For example waterless urinals not only reduce the building's water consumption, they also reduce the cost of installation by eliminating the need for water supply lines or flush valves. Pervious bituminous paving systems allow water to pass through the pavement and be absorbed naturally by the ground. This reduces the need for the installation of storm water collection systems, catch basins, storm water piping and storm water detention ponds. Light colored paints can be used along with lighting simulation programs to optimize paint color selection and lighting system design. This strategy resulted in a 25% reduction to the heating load from lighting on a Pennsylvania school. (Zeigler)

All the increased installation efficiencies found have resulted from manufactures striving to develop more efficient and more sustainable products. As new "green" products are developed, they will continue to aid in the effort to improve installation efficiency.

Continuing Research

The synergies and connections established in this paper between sustainable design and constructability provide an indication that many more are likely to exist. The core concept connections show some of the common threads between these concepts. Further research should focus on searching projects for other instances where sustainable design and constructability overlap. Identifying other examples will provide researchers and industry professionals with evidence that these are not rare occurrences. Common success factors should also be identified as well as the steps needed to take full advantage of the possibilities for increased efficiency.

The connections found between sustainable design and constructability aim to increase building efficiency and reduce waste. Is it possible to increase the efficiency of the design process and reduce wasted design efforts? Further research should explore how both sustainable design and constructability can be incorporated jointly into the design process. The combination of these processes has the potential to lead to substantial design process improvement.

Contracting and organizational strategies have also shown to be an important factor in the integration of sustainable design and constructability. Further research is needed to explore contracting strategies and project delivery methods to enhance the efforts and encourage the interaction of both concepts.

Conclusion

The synergy that can be achieved between sustainability and constructability is exemplified on the Pentagon renovation. The potential to improve the sustainability and the constructability of a project is enhanced when these two initiatives are integrated and approached in a combined fashion. An integrated and innovative organization was a key to the success of this effort on the Pentagon projects. The combination of these two initiatives is not typically undertaken on projects but should be addressed. When it is, a much better project is achieved in terms of its overall sustainability as well as the ease by which it is constructed.

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