LEAN AND GREEN: INTEGRATING SUSTAINABILITY AND LEAN CONSTRUCTION

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ABSTRACT

Sustainable construction promotes the efficient use of resources in the design, construction and use of buildings. Its emphasis is strongly on the resources related to the environment and health of building occupants. Hence, energy use, physical waste, environmental impacts as well as the creation of healthy and productive working environments are the focus of the sustainable building initiative.

Lean construction emphasizes the stripping away of non-value adding (*muda*) activity to leave only the value adding steps of a process. By doing this, lean constructors are able to produce different products with a limited amount of resources. The driving forces of this advanced production method are business focused: Profitability and market share.

It is argued in this paper that sustainable construction and lean construction have a common agenda for minimizing resource. This serves as a basis for combining the two initiatives. While the objectives of lean construction might be short-term oriented and the environmental concerns of sustainable construction longer-term, both have at their core the efficient use of valuable resources.

The viability of joining together lean and sustainability is explored in this paper. Points of connection and synergy are identified. It is proposed that the way sustainable design and construction are completed needs to be enhanced to ensure it continues to impact construction development. Moreover, advanced production methods like lean construction show that sustainable construction can have a much greater impact on resource efficiency in projects than it currently does.

KEYWORDS

Lean construction; Sustainable construction; Resources; Waste; Pentagon Renovation; Toyota

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INTRODUCTION

Sustainable (green) buildings are becoming known as high performance buildings because they promise to increase resource efficiency and reduce the impact built facilities have on the environment. Increasingly, owners and building occupants are demanding that new facilities be designed and constructed with sustainable features due to reduced life cycle costs, reduced energy use, improved occupant health and productivity, and more marketable facilities. Consequently, the U.S. Green Building Council has seen a huge increase in buildings registered under the LEED (Leadership for Energy Efficient Design) rating system. From 12 pilot projects awarded LEED certification in 2000, there are now 820 registered projects and 53 certified projects (LEED 2003).

The virtues and benefits of sustainable buildings are widely noted, but designing and constructing these facilities can be very demanding. For example, the practice of integrated design (also known as whole building design) assesses the impact of a design decision in one part of the building on all other parts in an attempt to optimize decisions over the whole facility (life cycle). This is admirable, but the design resources required to do this greatly exceed that of conventional design processes in an environment where economic pressures encourage fewer resources be used. In construction, recycling requirements can impose onerous activities to on site crews if the company does not have well-established recycling practices. Moreover, most sustainable projects are delivered using conventional project processes. These processes are the design, construction and procurement activities used to convert owner requirements into buildings. Very little advancement has been made in the execution methods of sustainable projects.

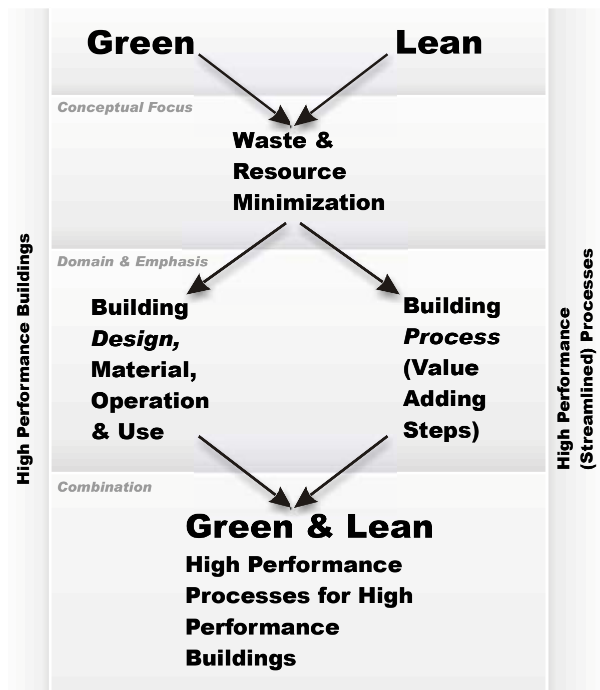
Lean production methods were developed in manufacturing to improve the efficiency with which products were created, and these provide insight for the design and construction of sustainable projects. The developers of lean production grappled with the issue of how to produce more efficiently products of more complicated design. Their solution focused on the efficiency of their design and production processes. By stripping away non-value adding (*muda*) activity to leave only the value adding steps of the process, substantially less production resources were needed.

By focusing on the value added activity of sustainable projects, better quality sustainable decisions can be made, and the demands of sustainable projects can be eased. This focus on value adding activity is provided to sustainable projects. This paper develops the connection between lean and green. It then explores this in case studies to highlight the benefits of more rigorous project processes for sustainable projects. These exciting case studies report projects at the renovation of the Pentagon and at Toyota Motor Sales that integrate lean production and sustainability. The case studies are important because others may have explored the conceptual connection between lean and green, but few have been able to show practical connections. The paper concludes with insights from the case studies and identifies areas for further research. The aim of this new research agenda is to develop high performance processes for sustainable (high performance) building projects.

CONCEPTUAL CONNECTION

Sustainable development and lean production both take a strong position on minimizing resource use as both “strive for the efficient use of resources through the reduction of waste” (Pulaski et al. 2003). This conceptual focus is illustrated in Figure 1 and establishes a compelling argument to draw the two initiatives together. On the one hand, sustainability emphasizes reductions in building energy use, water use, materials employed, and pollution. The economic case for sustainability initiatives is made on life cycle cost savings, as most sustainable systems tend to involve higher initial cost. For example, sophisticated light controls add to project costs, but save on energy costs over the life of the building. However, an integrated systems approach can help realize hidden cost reductions. Thus, lighting controls can also reduce the space heat load due to reduced excess lighting, and therefore contribute to a reduction in required cooling load which could result in downsized mechanical equipment. While smaller mechanical equipment incurs lower initial cost, this typically comes at the price of increased use of design resources, and added process complexity. On the other hand, lean production emphasizes reductions in the waste present in the processes used to design and construct buildings. The emphasis is in producing products valuable to the customer, while eliminating all other activities, defined as waste (*muda*). Thus, while both sustainability and lean focus on eliminating resource waste, sustainability focuses on the design of the building and lean production on the processes used for realizing the building. This is shown in the middle section of Figure 1. Merging these two initiatives together has great potential to enhance both.

FIGURE 1.
Conceptual Connection between Lean Production and Sustainable (Green) Development



The different emphases of the shared waste reduction agenda is important for understanding how sustainability and lean production can be weaved together to support a mutual benefit. While the additional design and added cost of more efficient equipment are often justified by paling to the life cycle savings of more efficient operation, significantly superior sustainable facilities can be created by improving the processes with which they are designed and constructed. Some of the improvements include the following.

- **Provide methods in execution that streamline project processes:** To combat the added burden of more complex designs, lean production provides methods based on production flows to eliminate excessive activity. For example, design activities are scheduled on information flows to reduce excessive design iteration.
- **Expansion of the focus on waste reduction:** No longer is waste in resource use and material fabrication the only emphasis, but design cycles, rework, documentation quality, the waste of incorrect decisions, wasteful construction practices, etc. – all of which impact the sustainability of the facility – are addressed.

- **Better sustainable projects by forcing an emphasis on value:** Many sustainable requirements are owner driven, but these requirements are not always in parallel with typical sustainable design practices. Areas of departure can lead to conflicts and tension between the owner and project team. Analyzing value more comprehensively will improve the delivery of these projects.
- **A new customer is introduced to the value equation:** The environment becomes a new customer to consider in the analysis of how the proposed facility adds value. If one building design reduces the negative impact on the environment over another, it is considered more valuable.

Lean production principles provide a clarifying focus on customer needs (value) in sustainable projects and ways to identify and eliminate activities that add no value (waste). At the conceptual level, this has been eloquently articulated by Hawken et al. (1999) in their seminal work *Natural Capitalism*. They emphasize the abilities of lean principles to achieve radical resource productivity (i.e., a 90% reduction in energy and materials intensity) and to fundamentally change the relationship between producer and consumer to a service and flow economy. These changes would allow sustainable development to be more economically attractive.

Others have drawn lean and green initiatives together. Huovila & Koskela (1998) argued that the sustainable goals of energy efficiency and reduced resource use need to integrate with traditional project goals of time, cost and quality. They suggested that maximizing value and minimizing waste through lean principles would help to achieve this wider set of goals. Degani and Cardoso (2002) also advocate drawing lean and green together. Vanegas (2000) provided a thorough description of how lean production could improve building life cycle performance. King and Lenox (2001) offered the only empirical study of the usefulness of combining lean and green. They addressed the issue of whether a firm adopting lean practices leads them to be better environmental performers. They found lean practitioners to be more likely to possess environmental management standards (i.e., ISO 140001), and systems to prevent (pollution) waste.

PRACTICAL CONNECTION

While one part of the compelling argument to draw sustainability and lean production together comes from dovetailing of lean and green at the conceptual level, the other part comes from the practical needs and benefits that result when it is done. Three case studies are used here to explore the practical implications of integrating lean and green.

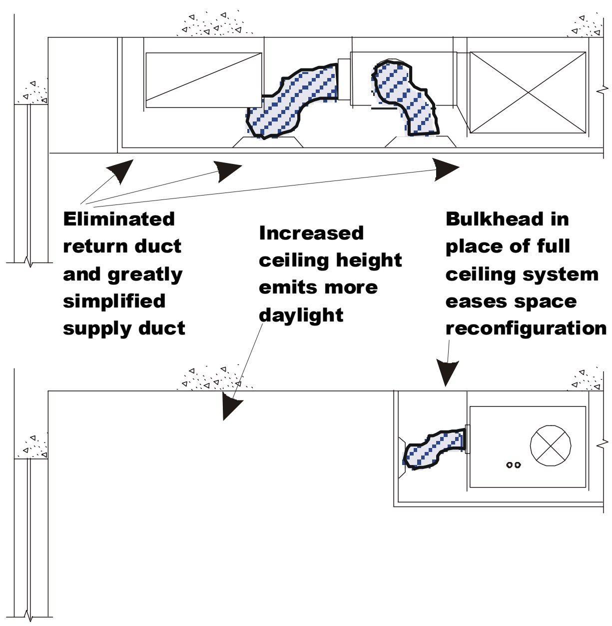
Pentagon Renovation I

The Pentagon is rapidly becoming one of the best examples of high performance buildings through its innovative design and use of processes. It is the world's largest office building and is being renovated in a series of projects totaling 12 years and $1.06 billion. The experiences of the Pentagon renovation highlight how lean processes impact levels of building sustainability.

The most compelling example of this is provided by the development of a Fan Powered Induction Unit (FPIU) for the Pentagon air conditioning system. This was designed by the mechanical design-build contractor to eliminate the use of return air ducts (Figure 3). However, the design also 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. This significantly improved the penetration of daylight. In addition, the FPIU reduced the number of mechanical rooms from 118 in phase one to only nine in phase two of the renovation. Consequently, installation was greatly streamlined and 20% cost savings were achieved. Over its life, the FPIU system is expected to reap energy savings of 9%. However, the true sustainable value and largest savings are the ability for future space reconfiguration without mechanical changes. Integrating design and construction processes early in the project enabled multiple and significant synergies to be realized between sustainability and construction process efficiency. This example highlights an emerging opportunity to enhance the sustainability of high performance buildings by improving the processes used to carry out these projects.

FIGURE 2.
Pentagon Renovation

FIGURE 3.
The Results of Process Efficiencies in Sustainable Design –
Conventional System (Top) Versus FPIU System (Bottom)

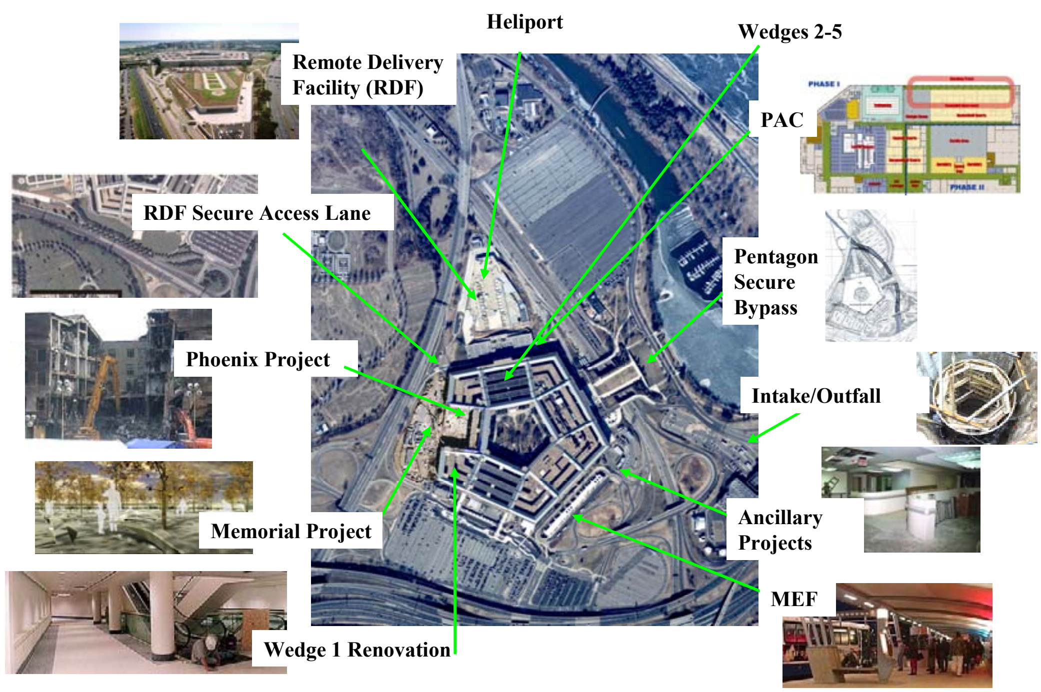


Pentagon Renovation II

The Pentagon renovation team is also developing expertise in the total project process for delivering their buildings. As shown in Figure 4, the Pentagon renovation consists of a number of projects, and each has built off the expertise of the projects before them. These projects have been completed using an innovative contracting strategy and delivery process designed to eliminate many contractual barriers that often inhibit innovation among designers and contractors and promote the type of behavior and performance that leads to highly efficient facilities that are completed within project budget and schedule. Highlights include.

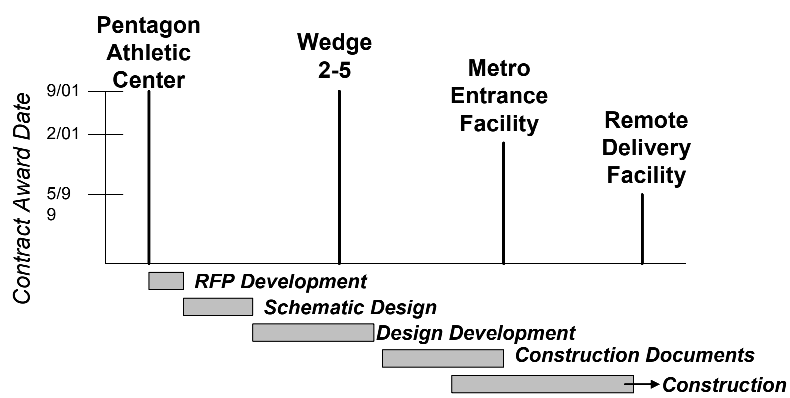
- **Design-build delivery:** Encouraged cross discipline interaction between designers and contractors from the beginning of design. The process supported the integration of building systems and encouraged design disciplines to work with contractors to determine the most efficient, practical and sustainable design solution.
- **Integrated Product Teams:** The Pentagon Renovation Program is organized internally in a matrix format with 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 IPT organizational structure creates a wholly integrated management structure that forces integration across disciplines, encouraging communication between project team members.
- **Performance based contracting:** Along with performance specifications, contracts were developed to support the design-build delivery process. For instance, in 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).
- **Fixed-price, award-fee contracts:** With no profit built in, this arrangement allowed contractors to be awarded a profit of up to 10 percent of the contract price. Shared savings and split overrun clauses are also used to provide additional incentives.

FIGURE 4.
Various Projects of the Pentagon Renovation Program



The numerous renovation projects at the Pentagon have been employed to upgrade the facilities to meet recent building codes as well as new security requirements. One of the major complexities with the project has largely been due to the requirement to keep the Pentagon fully operational throughout its renovation. However, this has permitted learning from earlier projects to be applied to later projects. Penn State researchers have been part of the Pentagon renovation team to capture and help implement this learning to improve the process. The most substantial learning concerns the timing, levels of detail, and best team members for addressing sustainable issues. The results of this learning are paying substantial dividends. Figure 5 identifies when in the design phase LEED was introduced on four of the Pentagon Renovation projects. Table 1 shows the LEED rating expected for each of these projects and the estimated cost associated with that rating. What can be seen is that the projects that addressed sustainability earlier in the process spent less money on the initiative and obtained higher ratings. The Pentagon renovation team developed better design solutions when they implemented sustainability requirements earlier in the project. Clearly the later projects reaped the benefits of experience in the earlier projects, however better timing was an important part of the learning and results achieved.

FIGURE 5.
Implementation of LEED in Pentagon Renovation Projects



Project Delivery Timeline -
Indicates when LEED was introduced to the project

TABLE 1.
LEED Project Goals and Cost Implications

Project	**LEED Project Goal**	**Cost Implications**
PAC	Gold	LEED was included in contract requirements. No additional cost currently reported.
W2-5	Gold	LEED was added as a goal, but not a requirement. No additional costs currently reported.
MEF	Silver	Total additional costs due to LEED changes $110,000
RDF	Bronze	Cx not complete two years after construction

Toyota, South Campus Project

The value of understanding the total process used to realize sustainable building projects is illustrated by a recently completed South Campus project at Toyota USA, Torrance, CA (Figure 6). Toyota has extended their corporate mission of environmental responsibility to their built facilities, through their Real Estate & Facilities group. This group has developed Process Green to encapsulate the environmental initiative. At the core of this initiative are material selection methods, environmentally-friendly design, and methods for motivating suppliers to adopt similar practices (known as “paying it forward”). Toyota also possesses a strong company culture of being lean, especially the use of continuous improvement (*kaizen*) to help manage and improve their processes. Kaizen is a key component of the Toyota Production System, the source of lean production (Ohno 1988; Shingo and Dillon 1989). These features provide the basis for a total process approach to sustainable project development that was used on the South Campus office building. The impact of this was a facility that achieved a gold LEED rating at a project cost of $63/s.f, which lies in the range of $54 to $76 of most Southern California office parks (Pristin 2003). The successful completion of this project has proved that high levels of building sustainability can be achieved with smart and effective project execution. This represents a significant advance in green building; because an increased budget rather than clever execution is thought to be the necessary ingredient for achieving sustainable goals. This new, leaner approach capitalizes on the execution opportunities available in projects resulting in high performance projects.

FIGURE 6.
South Campus Project, Toyota, Torrance, CA

INSIGHTS & FURTHER RESEARCH

The way project processes are formed is known to be critical to the success and failure of projects (Konchar and Sanvido 1998). Increasing research shows that the way project teams are composed, the relationships that are formed, the organization of the project, and the contracts used significantly impacts how projects are undertaken and the success of the project (AbulHassan 2001). The link between how sustainable projects are executed and levels of sustainability has some presence in the sustainability movement. Romm (1994), for instance, argues “up-front building and design costs may represent only a fraction of the building’s life cycle costs…(but) when just 1% of a project’s up-front costs are spent, up to 70% of its life-cycle costs may already be committed.” Wilson et al. (1998), in *Green Development*, note the development process advantages of sustainability. For example, streamlined approvals are likely with green developments because fewer community objections are encountered. While promising, these links need to be developed so that consistent advantage can be taken of them.

How projects are completed is a key to the success of sustainable projects. All three of the case studies presented showed this to be the case. The main insights from these projects are.

- **Understand where value is created:** The FPIU case study demonstrates that understanding what is valuable and what each customer regards as valuable is a significant source of innovation that can help to streamline projects and improve the solutions to many of the challenges faced in sustainable projects.
- **Integrated teams with innovative contracting and delivery strategies:** An integrated team approach with incentives to address the challenges of sustainable projects will bring out the best innovations and do so in streamlined way. Owners need to articulate their performance needs (the real value they desire in their new buildings) and allow their teams room to develop solutions. As the Pentagon projects are showing, this will maximize results (value) and do so in an increasingly leaner fashion (faster, with fewer resources expended).
- **Understand whole process:** Toyota's development strategy is showing that understanding the whole process can lead to better sustainability levels and efficient delivery of sustainable projects. Continuing to develop an understanding of the total process will provide new insight about the location of leverage points to induce the outcomes desired and ways to best exploit these.

Lean and green share a strong conceptual bond to reduce resource use and minimize waste. Integrating lean production principles, which focus strongly on process performance, into sustainable building projects will enable further understanding to be developed regarding how best to complete sustainable projects. By focusing on the value added activity of sustainable projects, better quality sustainable decisions can be made, and the demands of sustainable projects can be eased. The case studies in this paper have shown that this can improve the levels of sustainability achieved in buildings as well as streamline the methods used to realize them. Further research should focus on improving the integration between lean and green, developing new tools, and better metrics for measuring activity in these projects. The integration of lean and sustainability is an exciting development with significant promise to improve building development.

REFERENCES

AbulHassan, H.S. (2001). "A framework for applying concurrent engineering principles to the construction industry." Ph.D. Dissertation, Department of Architectural Engineering, The Pennsylvania State University, University Park, PA.

Degani, C.M. and F.F. Cardoso. (2002). "Environmental performance and lean construction concepts: can we talk about a 'clean construction'?" Proceedings of the 10th Annual Conference on Lean Construction: IGLC-10, Gramado, Brazil, pp. 115-127.

Hawken, P., A. Lovins, and L. H. Lovins. (1999). Natural capitalism: creating the next industrial revolution. Boston: Little, Brown and Company.

Huovila, P. and L. Koskela. (1998). "Contribution of the principles of lean construction to meet the challenges of sustainable development." Proceedings of the 6th Annual Conference on Lean Construction - IGLC '98, Guarujá, Brazil.

King, A. and M. Lenox. (2001). "Lean and green? An empirical examination of the relationship between lean production and environmental performance." Production and Operations Management, Vol. 10, No. 3, pp. 244-256.

Konchar, M. and V. Sanvido. (1998). "Comparison of U.S. Project Delivery Systems." Journal of Construction Engineering and Management Vol. 124, No. 6, pp. 435-444.

LEED. (2003). "LEED registered project list, LEED." www.usgbc.org/LEED/Project/project_list_registered.asp. Accessed: June 23, 2003.

Ohno, T. (1988). Toyota production system: beyond large-scale production. Portland, OR: Productivity Press.

Pristin, T. (2003). "Toyota's new main campus: green goes mainstream." The New York Times, pp. C6.

Pulaski, M.H., T. Pohlman, M.J. Horman, and D.R. Riley. (2003). "Synergies between sustainable design and constructability at the Pentagon." Proceedings of the Construction Research Congress (CRC), winds of change: integration and innovation in construction, Honolulu, HI.

Romm, J.J. (1994). Lean and clean management: how to boost profits and productivity by reducing pollution, Singapore: Kodansha International.

Shingo, S. and A.P. Dillon. (1989). A study of the Toyota production system from an industrial engineering viewpoint. Cambridge: Productivity Press.

Vanegas, J. (2000). "Sustainability: a blueprint/greenprint for action." NATO Advanced Research Workshop: Green Engineering and Management Methods and Tools for Central and Eastern Europe, Budapest, Hungary.

Wilson, A., J.L. Uncapher, L. McManigal, L.H. Lovins, M. Cureton, and W.D. Browning. (1998). Green development: integrating ecology and real estate. New York: John Wiley & Sons.