SUSTAINABLE VALUE ON CONSTRUCTION PROJECT AND APPLICATION OF LEAN CONSTRUCTION METHODS

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ABSTRACT

Lean Production is a systemic approach to meeting customer expectations, whatever they value, by reducing waste. At first glance, Lean then could only contribute to sustainability, but in fact sustainability is achieved only if the customer values sustainability. One intention of this paper's authors is to examine whether sustainability is feasible as an added value. Another intention is to examine how current Lean construction tools and methods impact the construction and operation of sustainable facilities. The last is to suggest how these Lean construction tools and methods have evolved to contribute to green construction. The authors reviewed the publications which study both Lean Principles and Practices, and the impacts on the economic, social and environmental sustainability. The paper also investigated the relationships between Lean construction methods and its impacts, which were identified with suggestions for future research.

KEY WORDS

Lean construction, sustainable construction, sustainable assessment, Sustainability

INTRODUCTION

The construction industry is one of the largest and most important industries, yet at the same time is one of the largest polluters (Horvath, 2004). Therefore, the construction industry has a major potential in the advancement of sustainable development. Lean construction may be one approach to sustainable construction by introducing the social and environmental issues as new values to achieve rather than focusing on just the accidental benefits of Lean construction to the environment.

The most widely accepted definition of sustainable development is from the Brundtland Commission which was set up by the United Nations. In the commission's report, *Our Common Future* (1987), the Commission defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Sustainable development does not focus only on environmental issues. More broadly, sustainable development policies and practices cover three areas: economic, environmental and social. The term, "triple bottom line" evolved as a basis for sustainable development (Elkington, 1997). In practical terms, the triple bottom line expands the traditional company reporting framework, the income statement, to take into account

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environmental and social performance in addition to financial performance. He proposed these three values for the strategic decision-making.

Some people may ask Lean practitioners whether Lean is green. The answer depends on whether customers recognize Lean's value. Many researchers have reported that Lean construction increases environmental benefits by eliminating waste, preventing pollution and maximizing the owners' value (Huovila and Koskela, 1998; Lapinski et al., 2006; Luo et al., 2005; Ferng and Price, 2005; Riley et al., 2005). Yet others have reported no appreciable relationship between Lean and green in the manufacturing industry (Helper et al., 1997). Several studies even argue that Lean shows a negative impact on environmental performance (Cusumano, 1994; Rothenberg et al., 2001). Since the main purpose of Lean methods is to provide excellent value for the customer rather than to reduce environmental impact, Lean does not always assure a positive environmental impact. Therefore, the question mentioned before is not appropriate and may need to be modified.

Does Lean contribute to sustainability? Lean can contribute to sustainability, but only if and when the customer values sustainability. Lean is a systemic approach to meeting the customer's values whatever they value.

The purposes of this paper are to examine how the current Lean construction methods impact the sustainability of high performance facilities and to suggest how these Lean construction methods evolve to contribute to green construction.

In this paper we are reviewing the publications which study both Lean and sustainability. We are identifying the relationships between Lean construction methods and impacts by the facilities for the purposes of sustainability. We also are suggesting more Lean construction methods that might have sustainable potential for green facilities.

THE CONCEPTUAL RELATIONSHIPS BETWEEN LEAN PRINCIPLES AND SUSTAINABLE CONSTRUCTION

While Lean construction literature has mainly focused on dealing with problems and challenges that arise on the construction site, some research has investigated Lean construction from the view of the whole life cycle of a project. It has been insisted that the Lean philosophies offer the conceptual basis, and Lean construction methods and tools have great possibilities for sustainable construction (Huovila and Koskela, 1998). They argued that Lean design deals principally with informational processes. On the contrary, Lean production emphasizes material processes and the flow view, thus eliminating waste is important. Moreover, the principles of Lean construction contribute to the sustainability objectives by:

- Eliminating (material) Waste → minimizing resource depletion and pollution
- Adding Value to the Customer → minimization of resource depletion, pollution, and matching business and environmental excellence.

While some research focused on cooperative benefits in economic, social and environmental perspectives of Lean philosophies (Hawken et al., 1999), most studies focus on Lean construction methods as a means of reducing initial costs and eliminating waste rather than increasing the environmental performance of the project (Lapinski et al., 2006; Degani et al., 2002; Horman et al., 2004; Riley et al., 2005). The effectiveness of Lean tools and methods is limited in these studies to the economic needs and values of the customers although new customers are recognized as economic, social, and

environmental values. Their main concerns are how the environmental benefits may be achieved with no additional upfront costs. The relationship has been demonstrated between sustainable development and Lean production (Horman et al., 2004). The authors compare these two goals. While the area of sustainability focuses on the design of the building, Lean focuses on the construction process. Considering that most practices of Lean construction deal with the problems on construction sites and that Lean philosophies consider controlling production a key activity, this idea seems reasonable at first glance. However, limiting the role of Lean within the construction phase fails to take into account the Lean Project Definition and Design phases in the early stages of a project. Moreover, it restrains the evolution of Lean. Lean practices could be implemented in the design phase of the construction projects to reduce costs and enhance sustainability. For instance, Value Stream Mapping may cover all the way from the design to the construction phase.

Figure 1. illustrates the conceptual relationship between Lean and sustainability. The four interconnecting phases of the Lean Project Delivery System (LPDS) extending from project definition to design, supply, and assembly are used to illustrate the Lean construction process (Ballard, 2000). Addressing sustainable issues, such as economic, social, and environmental values as the requirements of an owner, Lean may act from the project definition to the construction phase for a sustainable facility.

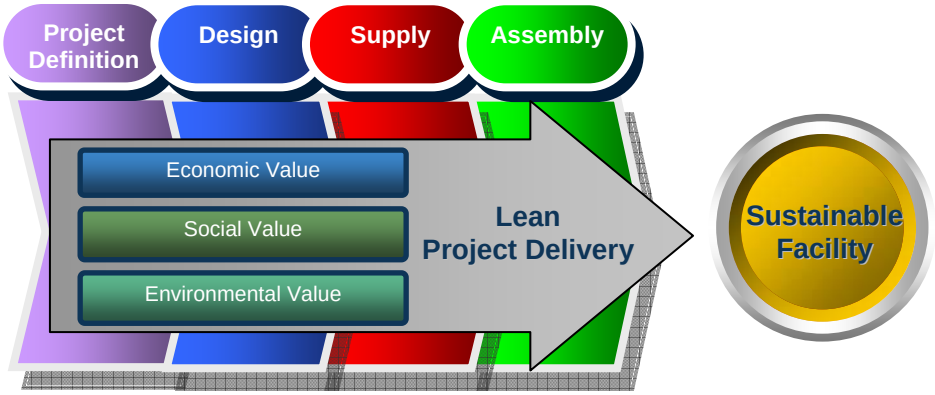

Figure 1. Conceptual relationship between Lean and Sustainability

THE PRACTICAL RELATIONSHIPS BETWEEN LEAN METHODS AND SUSTAINABLE IMPACTS

The same four interconnecting phases of the LPDS are used to provide a framework for the implementation of Lean construction methods in the construction industry. This section will address how Lean construction methods would be applied to construction projects and how these methods contribute to the sustainability in the projects.

LEAN PROJECT DEFINITION

Value Determination

Defining value and waste is critical in Lean production. Value management in Lean production is an attempt to maximize value and eliminate waste. Recently more studies have introduced the environment as an additional "customer" for sustainable facilities (Horman et al., 2004; Lapinski et al., 2005). In these studies the environmental values include: minimal building impact, maximum building system efficiency, efficient energy

usage, reduced waste, and a healthy and productive environment for occupants. The social impact of facilities has been one of the critical concerns in the architecture industry. It is hard to measure the social impacts of facilities on humans and communities. Further, the results of the measurements may be somewhat subjective. Architects and landscape designers, however, have been studying social, cultural, and ethical impacts, such as changes in human behaviour, the health of occupants, and community relations. The social impacts of facilities are of little interest in the construction industry. Sustainability includes the social bottom line, as well as economic and environmental bottom lines. Lean construction needs to identify sustainable values including economic, environmental and social values as critical factors in implementing sustainable construction.

Contracts and Delivery Methods for Lean Construction

The contract type and delivery method of a construction project do not appear to impact directly on the sustainable construction of facilities. However, selecting an appropriate contract type and a delivery method for a construction project provides the basis for the sustainability of the facilities indirectly by eliminating contractual barriers that prevent communication and innovation among designers and contractors. Several innovative contract types and delivery methods are considered to provide a good environment for sustainable construction: integrated product teams/cross functional teams and Performance-based Contracting (Horman et al., 2004).

The Integrated Product Teams (IPTs) are an approach that integrates an organization across disciplines, encouraging communication between project team members. This method increases the owners' sustainable benefits by incorporating each discipline's opinions about maximizing sustainable performance and reducing the costs of the green facilities. This method also reduces preventable costs due to unnecessary reworks caused by miscommunication among stakeholders.

Performance-based Contracting is a technique which defines all aspects of an acquisition around the purpose and required performance of facilities, not the construction process. Green facilities usually require inventive techniques and materials that are difficult to adopt for inexperienced architects or engineers. Therefore, the information regarding these techniques and materials should be provided by specialty contractors and suppliers in the design phase of the construction project. This method helps the specialty contractors and suppliers suggest innovative ideas in the early phases of a construction project for the sustainable performances that the owner requires.

Design-Build-Operate-Maintain (DBOM) is another way for an operations & maintenance (O&M) provider to participate actively in the early phases of construction (Dahl et al., 2005). Design-Build-Operate-Maintain is a project delivery system facilitating O&M providers to participate in design-phase project teams. As a result of this activity this system has the, "…potential for increasing maintainability, as well as sustainability", (Dahl et al., 2005).

Target Costing is not examined for the purpose of sustainability. This Lean method, however, may contribute to sustainable construction. Target Costing in the construction industry is the practice of allocating the maximum of a construction budget for the construction sub-phases or the functions of a facility. This practice prevents the possibility of an unnecessary increase in facility performance, and a waste of resources with pre-specified functions, capacities, and specifications.

LEAN DESIGN

Design is a process incorporating various construction techniques and materials to produce value to an owner. This process is very important considering the impacts to the overall life of a facility. Design in a sustainable construction project is especially critical because green materials, resources, and construction technologies are relatively innovative and requires comprehensive coordination for the best application in green facilities. The impacts of this phase on the O&M phase are remarkable. One researcher suggests that a mere one percent of the initial costs in the early phase of a project addresses seventy percent of its life cycle costs (Romm, 1994).

In order to minimize environmental impacts and energy consumption during construction of sustainable facilities, several Lean design methods could be implemented: Integrated Design (Whole system design), Design for Maintainability (DFM), Set-based Design, Target Costing, and 3D Modelling.

Integrated Design is one of the most critical methods for sustainable construction (Hawken et al., 1999; Riley, 2004; Horman et al., 2004; Lapinski et al., 2005). A key feature of this method is to integrate various green materials and construction technologies by encouraging stakeholders in the design phase for maximizing the sustainability of a facility while reducing the need for energy, equipment, or resources. As other Lean methods have evolved for sustainable construction, integrated design practices should be modified for environmental purposes (Horman et al., 2004). "Integrating design and construction processes early in the project enabled multiple and significant synergies to be realized between sustainability and construction process efficiency" (Horman et al., 2004). Moreover, early involvement of specialty contractors and suppliers in the design phase allows more possibilities for sustainability of a project (Riley et al., 2005).

Design for Maintainability (DFM) is a design strategy focusing on the reliability and ease of maintenance of a facility (Dahl et al., 2005). These methods increase the importance of O&M in the design phase of a facility. Operations & maintenance (O&M) costs are the largest portion of the total expenditures over the life of the facility, typically accounting for 60~85% of the life cycle cost. The safety and wellbeing of the occupants and of a community can be ensured by addressing social issues during the design phase in a sustainable construction project. Moreover, these social benefits may improve external images of the sustainable construction project.

Set-based Design has the possibility of contributing to sustainable construction, although it has also not been examined for sustainability. This method explores all possible solutions prior to the last responsible moment. This strategy seeks various alternatives in order to avoid the risk of enormous rework and wasted effort.

LEAN SUPPLY

Just-in-time (JIT) could also be either an environmentally-friendly method or not. Just-in-time reduces damage and materials (Riley et al., 2005). Moreover, this method may reduce the various sources of extra inventory. At the same time, however, the frequent transportation of inventory and materials may cause volatile organic compounds (VOCs) and CO2 emissions. Several Lean plants have recognized that a Just-In-Time strategy has caused more air emissions of VOCs in the plants, while contributing flexibility of operations and reducing inventory level (Rothenberg et al., 2001). Therefore, the plants have reconfigured some of their Lean management principles to reduce their air pollution emissions. They started to increase painting batch sizes in order

to reduce air emissions of VOCs in the plants, despite the fact that it conflicts with the JIT practices of the plants. Even though applications in the manufacturing industry and construction industry are not exactly the same, we need to notice the probabilities and possibilities of bad environmental impacts from Lean adaptation. The consideration from the holistic perspective is required to increase the sustainability of a construction project.

LEAN ASSEMBLY

Prefabrication may be one procurement method for sustainable construction. Economic, social, and environmental indicators from Horman et al. examined the impacts of prefabrication for purposes of sustainability using these indicators (Horman et al., 2005 in Luo et al., 2005). The features of prefabrication on sustainable constructions include:

- Increased potential of improved supply chain integration of green materials
- Safer working conditions
- Reduced environmental impact due to transferring workers, machines, staked materials, temporary structures and onsite activities to a prefabrication plant
- Easier recycling of materials in an off-site environment
- Enhanced flexibility and adaptability
- Reduced overall life cycle cost
- Reduced economic impact in local communities

Prefabrication may have both sustainable benefits and disadvantages depending on the exact conditions of a project. These impacts fall into three categories: economic, social, and environmental. Thus, economically, one advantage is the reduced cost of prefabricated units as opposed to on-site units. Socially the working conditions are safer and more stable in prefabricated construction than they are on-site. Environmentally, this method may improve the supply chain for green materials, one aspect of green facilities.

Yet, there are some problems as well. Economically, and socially, less local labour is needed, thus the salaries of the workers do not contribute to the local economy. Environmentally, this process may consume more energy for transportation of prefabricated products and emit more air pollution.

A contractor implementing sustainable construction should identify both benefits and disadvantages of prefabrication and reference them for the selection of the best procurement method using a holistic view over the life cycle of a project.

EXECUTED OVER THE WHOLE DELIVERY PROCESS

Visual Management

There are several Lean visual methods which could help sustainable construction. They include: the 5Ss and Value Stream Mapping (VSM) or the streamlining of the process.

The 5Ss, which are *separate, straighten, scrub, systematize, and sustain/standardize* are used to create and maintain a clean, orderly, and standardized work place. This method is often considered the first step companies take in their Lean journeys, since it serves as the foundation of future continual improvement efforts. The U.S. Environmental

Protection Agency (US EPA) in 2006 expanded the 5Ss to the 6Ss by adding safety to the five pillars of the visual workplace in the Toyota Production System. Although adding safety to the 5Ss is somewhat unnatural and factitious, it expands the scope of the 5Ss from efficiency to sustainability by adding safety to the operation. The 6Ss may help a contractor increase productivity while protecting labour from injuries and occupational health hazards by providing clean and accident-free work areas.

Many studies suggested that VSM shows both information and the production process, and so is one of the best visual tools for stakeholders to understand the generation and flow of value and waste during project processes for sustainability of the facilities (Riley et al., 2005; Lapinski et al., 2005, 2006). Traditionally VSM assesses process time and inventory levels to define value and waste, because these factors are key constituents for economic purposes. It is hoped that this approach would improve the process of production by eliminating economic waste. This Lean method, however, may be used not only for economic purposes, but also social and environmental purposes by adding sustainability-related data into the map. Not only time and inventory, but also the waste of resources, creation of pollution, resource consumption, safety, and interaction with the community may be mapped. In 2006, the US EPA incorporated the traditional VSM with environmental considerations. This new method developed a "materials line" on the bottom of a value stream map that shows two types of data:

- The amount of raw materials used by each process
- The amount of materials that end up in the product and add value from a customer's perspective.

The materials line is similar to the "time line" on traditional value stream maps, and can be developed for any type of resource (e.g., water, energy, total materials, and/or a critical substance used in the product), environmental pollution (e.g. emissions, waste, wastewater, and hazardous wastes) or social impacts (e.g. noise, relationship with the community).

In order to identify an owner's capital development process over the whole project, an extended VSM covering the programming to the operational phase was developed (Lapinski et al., 2005). This map was used to recognize the environmental value and waste of a sustainable construction project.

Kaizen and Kaikaku

Kaizen, which means continuous improvement in Japanese, is a core component of Lean production not only for economic purposes, but also for social and environmental purposes in sustainable construction. This practice is a primary means of implementing other Lean methods, ranging from the 5Ss to much more complex Lean construction tools. After the analysis of the current status, Kaizen is useful for continuous improvement by using a delivery process mapping method (Lapinski et al., 2005). Kaizen provided the basis for a total process approach to sustainable project development that was used at the South Campus Office Building project in Torrance, CA (Horman et al., 2004). Kaizen plays a key role in improving the current status for sustainable construction. All sustainable indicators may be improved through Kaizen.

Another potential tool for sustainable perfection is Kaikaku. Kaikaku (Kaizen events), means a rapid process of improvement, is a team activity designed to eliminate waste and make rapid changes for product and process improvement in the workplace. This strategy

is employed to get workers with multiple organizational functions on different levels to unite in improving processes and addressing problems. When implementing chosen improvements, the team rapidly employs inexpensive solutions usually within three days. It is possible for opportunities rapidly to be created by changing the process. Kaikaku can create reduced pollution and material waste. Environmental Health and Safety staff must participate in Kaizen events due to the possibility of non-compliance and exposure of workers to hazards. Suggestions may be made by EHS staff to facilitate the process (US EPA, 2006).

ASSESSING LEAN CONSTRUCTION METHODS ON SUSTAINABILITY

In the construction industry there are few performance measurement tools which may link Lean efforts and green results directly, because it is hard to measure all sustainable impacts of Lean implementation. For instance, in order to measure the performance of the integrated design, all measurable benefits should be counted (Hawken et al., 1999). Traditional construction performance measurement systems with fragmented views may miss the benefits from integrated design. In the holistic perspective integrating expensive sustainable resources and technologies could reduce overall upfront construction costs.

The challenge to measuring sustainability is that sustainability is not very quantifiable (Kwong, 2004). Therefore, it is very difficult to quantify both direct and indirect impacts of sustainable features, including initial cost savings, energy savings, O&M savings, productivity improvement, improved relationship with the community, water consumption, pollution, safety, and prestige. Moreover, it is more difficult to identify the comprehensive link between Lean implementation and sustainability.

Table1. Lean methods and sustainable impacts

Lean Project Delivery Phases	**Methods/Tools**	**Sustainable Impacts**		
		Economic	**Social**	**Environmental**
Lean Project Definition	Integrated Product Teams	O	O	O
	Performance-based Contracting	O	O / X	O / X
	DBOM	O	O	O
	Target Costing	O	O	O
Lean Design	Integrated Design	O	O	O
	Design for Maintainability	O	O	O
	Set-based Design	O	-	O
Lean Supply	JIT	O	-	O / X
Lean Assembly	Prefabrication	O / X	O / X	O / X
Over Whole Delivery Process	5Ss/6Ss	O	O	O
	Value Stream Mapping	O	O	O
	Kaizen	O	O	O
	Kaikaku (Kaizen events)	O	O	O

O: positive impacts; X: negative impacts; O/X: Both positive and negative impacts; -: no impact

Table1. illustrates a quantitative assessment of the previously discussed methods on the sustainability of a construction project. Most lean construction methods provide positive economic impacts for sustainable facilities while showing several no-impacts or negative impacts on social and environmental aspects. The table shows concrete relationships between the Lean construction methods and the sustainable construction of a facility, while several Lean construction practices reveal no relationship or negative relationships. Environmental and social impacts do not tend to be directly felt by the stakeholders in a particular project (Yates, 2001). They are harder to trace to a specific operating method rather than to allocate to an operating method. Stakeholders, therefore, ignore the social and environmental impacts and remove them from the decisions of a commercial facility construction project.

CONCLUSION

Lean philosophy provides a concrete basis not only for economic, but also social, and environmental purposes in sustainable construction by improving the delivery processes of green facilities. This paper demonstrates that high levels of building sustainability can be achieved with smart and effective project execution resulting in fewer additional upfront costs from the qualitative perspective.

The key impacts of using Lean construction methods for the purpose of sustainability are categorized as follows:

- Economic perspective: possible upfront cost reduction, resource savings, operating cost reduction, and high performance capability
- Social perspective: workplace safety, occupant health, community wellbeing, loyalty among stakeholders, and external image improvement
- Environmental perspective: reduced resource depletion, pollution prevention by eliminating waste, and resource preservation.

Several Lean construction methods are examined in this paper. Although many other Lean construction practices are not examined for sustainability, these practices yet have a possibility for sustainable purposes but need their impacts to be quantified. The difficulty in understanding and quantifying the impacts of the Lean construction methods is perhaps one reason that stakeholders hesitate to introduce the Lean construction methods to achieve sustainable facilities. This is one reason most publications assess Lean construction methods only from the economic perspective. Further research will be conducted regarding quantifying not only the economic, but also social and environmental impacts of Lean construction methods, and developing a framework to support the selection of various Lean construction practices for sustainable facilities.

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