Lean and green: emerging issues in the construction industry – a case study

Wu Peng[1] and Low Sui Pheng[2]

Abstract

The construction industry plays a significant role in economic growth, both directly through its activities, and indirectly through the provision of buildings and infrastructures for the smooth functioning of businesses. However, the construction industry is highly challenged as a 3D's industry – dirty, dangerous and demanding. Lean production focuses on eliminating waste and maximizing productivity through the pull system, employee involvement, continuous improvement, etc. Much has been discussed about the waste elimination and productivity improvement that can be achieved by applying the lean concept. However, as the consideration of the environment is becoming an increasingly important part of the construction culture, there is a need to investigate the applicability of the lean concept to achieve environmental sustainability, which is often used interchangeably with the term "green".

This research therefore aims to investigate the contribution of the lean concept to achieve low-carbon installation in the construction sites using precast concrete products. The results show that the lean concept can be adopted to reduce carbon emissions in terms of re-designing the site layout, improving the supply chain and the installation work flow. Some on-site construction activities can be improved when examined by the lean thinking. Based on the results, the construction industry can obtain better understanding of the lean principles to meet the pressing environmental regulations.

Keywords: lean, green, prefabrication, carbon emissions

Introduction

Among all current environmental issues, climate change seems to be the most significant one, which causes considerable threat to human development (Tang and Yeoh, 2007). The worst-case predictions for rising sea levels in the Thames Estuary would see the level of the river rising by up to four metres by 2100, which means that eventually, large parts of London – one of the world's business capitals – would be under water (Tang and Yeoh, 2007). Billions of people are exposed to natural disasters caused by global climate change, which takes lives, damages infrastructures and resources, disrupts economic activities and threatens social development (Pelling et al., 2004). The potential impact of climate change on the global economy may be enormous: re-insurance companies estimate that it can be of the order of hundreds of billions of dollars per year in the form of natural disasters and disruptions to agricultural cycles (Brown, 2005). If actions are not taken to reduce greenhouse gas emissions, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP per year, now and forever (Stern, 2007).

With the rising recognition of global climate change, the construction industry is now under increasing pressure to take environmental considerations into the daily decision-making processes. The rise of the global focus on climate change leads to the foundation of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 to

[1] Ph.D. Candidate, Department of Building, National University of Singapore, 4 Architecture Drive, Email: g0700346@nus.edu.sg

[2] Professor, Department of Building, National University of Singapore, 4 Architecture Drive, Email: bdglowsp@nus.edu.sg

address the environmental concerns that are brought about by global climate change. UNFCCC aims to introduce measures to control adverse climate changes caused by greenhouse gases (GHGs) in both industrialized and developing countries (Yates, 2007). Global environmental concerns about climate change also leads to the establishment of the Kyoto Protocol, an international agreement that sets binding targets for the reduction of GHG emissions by industrialized countries by the year 2012 (Yates, 2007). The Kyoto Protocol is regarded as a small step towards stabilizing atmospheric concentrations of greenhouse gases at a level that will have acceptably manageable consequences on the global environment, human health, natural resources and physical infrastructure (Tang and Yeoh, 2007).

The construction industry is constantly being challenged to reduce its large amount of energy consumption, raw material, and water usage (Low et al., 2009). According to Klotz et al. (2007), buildings consume 36 percent of the total energy used, 30 percent of the raw materials used and 12 percent of potable water consumed in the USA. American Institute of Architects (2007) estimated that nearly 50% of all the GHG emissions are generated by buildings and their construction in terms of the energy used in the production of materials, transportation of materials from production factories to construction sites, as well as energy consumed in the operational stage. However, there is considerable potential to control and reduce carbon emissions in the construction industry with appropriate management. This will not only help the construction industry to meet regulations that curb carbon emissions, but can also bring significant benefits to the construction companies. For example, according to the Singapore Institute of Surveyors and Valuers (2008), the Clean Development Mechanism (CDM) Documentation Grant, where S$100,000 worth of funding will be provided to encourage companies to develop CDM projects in Singapore, has been launched by the National Environment Agency (NEA). In addition, carbon trading funds worth more than 250 million euros (S$532.4 million) may be listed by the Singapore government for the building sector in the near future.

Many attempts have been made to reduce carbon emissions to achieve long-term sustainable development, including process and technology innovation (Spence and Mulligan, 1995), adopting low-carbon fuels (Hendriks et al., 1999), identifying alternative low-carbon raw materials (Ellis, 2004) and CO_2 capture and sequestration (Herzog, 2001). However, it should be noted that the nontechnical issues should not be overlooked when reducing carbon emissions, i.e. the improvement at the managerial level. Instead of relying solely on the carbon reducing technologies, project managers should be able to adapt to an open system where both the technical and nontechnical improvements are balanced. This research therefore aims to: a) to highlight the relevance of the lean thinking in low-carbon erection in the construction sites using precast concrete products; and b) to examine how the lean thinking can be successfully applied in the construction sites using precast concrete products to achieve low-carbon erection. It should be noted that the term "CO_2" can be used interchangeably with other green indicators, such as energy efficiency and waste. An in-depth case study of one construction project in Singapore will be examined for this purpose.

Lean production philosophy

Originated from the Toyota Production System (Ohno, 1988), the core of the lean production philosophy was the observation that there were two aspects in all production systems: conversions and flows (Koskela, 1992). Conversion activities referred to those which actually added value to the product/process. Flow activities referred to non-value adding activities which consumed time and resources but did not add value to the product/process. Traditional management improvement was not fully aware of the existence of these non-value adding activities, leading to efficiency being lost during production processes. The lean production philosophy aimed to create an environment where conversion and flow activities were treated separately. Conversion activities were improved while flow activities were eliminated.

The lean concept advocated that the production process should not only cover internal production matters but also satisfy customer needs, i.e. to generate value for customers (Drucker, 1989). The principles of value generation in lean production included (Koskela, 2000):

1. Requirements capture. Requirements capture was requisite to generate value.
2. Requirements flow-down. The requirements of the customer must be available in the production life cycle.
3. Comprehensive requirements. The comprehensive requirements meant that all deliverables to the customer should be taken into consideration in the requirement flow-down.
4. Ensure the capability of the production system. This principle meant that even though the requirements of customer could be transferred in the production life cycle without value loss, the production system must obtain the capability to design, produced and deliver products as required by the customer.
5. Measurement of value. Measuring value generated by the production process to the costumer was of critical importance for further improvement (Whiteley, 1991).

The tenets of lean production were drawn by Womack and Jones (1996), including:

1. Specify value by product. According to Howell and Ballard (1998), specifying value by product shaped all actions around customer requirements.
2. Identify the value stream. A value stream map was usually adopted to help project managers to identify the hidden issues that might hinder the flow of the activities.
3. Make production flow. It means that the production process should not be interrupted. The products should be in constant motion without stopping.
4. At the pull of the customer.
5. While pursuing perfection – custom product, zero time delivery, nothing in stores.

The lean concept has proven to be effective in increasing environmental benefits by eliminating waste, preventing pollution and maximizing the owners' value (Huovila and Koskela, 1998; Riley et al., 2005; Ferng and Price, 2005; Luo et al., 2005; Lapinski et al., 2006). Huovila and Koskela (1998) examined the contribution of the lean construction principles to sustainable development. The contributions included minimization of resource depletion, minimization of pollution and matching business and environmental excellence (Huovila and Koskela, 1998). EPA (2003) found that lean produced an operational and cultural environment that was highly conducive to waste minimization and pollution prevention, and that lean provided an excellent platform for environmental management tools such as life cycle assessment and design for environment. Luo et al. (2005) applied the lean concept to prefabrication and stated that lean could contribute to improve quality and supply chain and reduce waste. Bae and Kim (2007) found that different lean applications might have different results on the three pillars of sustainable development (i.e. economic, social and environmental sustainability). For example, lean supply might have influence on economic and environmental impacts rather than social impacts. Nahmens (2009) stated that it was a natural extension to apply the lean concept to achieve green production and construction. By applying the lean concept to a production line, 9 to 6.5 people (labor waste), 12% space (equipment waste) and 10% wallboard (material waste) could be reduced (Nahmens, 2009).

However, there were a few studies which argued that lean may show a negative impact on environmental performance (Cusumano, 1994; Rothenberg et al., 2001). Helper et al. (1997) also stated that there was no appreciable relationship between lean and green in the manufacturing industry. It should be noted that the evaluation of the lean concept in achieving environmental sustainability could only be examined when the environmental sustainability was set at the target at the very start. The contribution of the lean concept to green could not be fully assessed when reducing initial costs and eliminating waste were set at the targets.

Research methodology

This study is part of a larger study that included, among other things, the production process of the precast concrete columns in precast concrete factories, the findings of which are presented in Wu and Low (2011). The precast concrete column weighs 1.864ton and the embodied carbon of the precast concrete column is estimated to be 609.59 kg.

The case study approach was adopted to examine how the lean concept could be applied in the precast concrete construction sites to reduce carbon emissions. A four-day site investigation was conducted in a condominium project of a contractor in Singapore, who is referred to as Contractor A in the following context. Data collection in the case study relied on many sources of evidence, including documentation, semi-structured interviews and direct observations:

1. Documentation information relating to the installation procedure, quality control procedure and waste records were referred to in the case study.
2. During the site investigation, semi-structured interview was requested with the project manager of Contractor A to rate the frequency and impact of the non-value adding activities in the precast concrete construction site that was obtained from literature review. The frequency of the non-value adding activities was rated using a Likert scale of 1 to 5: (1) Never; (2) Rarely; (3) Occasionally; (4) Often; and (5) Always. Similarly, the level of impacts of the non-value adding activities was rated on a scale from 1 to 5: (1) insignificant detrimental effect; (2) minor detrimental effect; (3) moderate detrimental effect; (4) significant detrimental effect; and (5) catastrophic effect. The severity of the non-value adding activities could therefore calculated by multiplying the frequency with the impact, as suggested by Williams (1993). This paper only presents the non-value adding activities with high severity as rated by the project manager.
3. Information related to waste of raw materials, waste of finished products and energy consumption caused by the non-value adding activities were recorded by direct observations.

Results

Site layout design

From the lean perspective, there are several areas that can be improved in the precast concrete construction sites to achieve low-carbon installation. By using both on-site fabrication with off-site fabrication, economic savings could be achieved for the contractor A. However, the design of the area for on-site fabrication should be conducted carefully.

The site layout plan of Contractor A is shown in Figure 1. In the construction site of Contractor A, the following procedure could be taken to improve the workflow from a lean perspective:

Step 1 – Re-allocate Tower Crane 1 (TC1) to achieve immediate usage of the precast concrete products produced in the on-site fabrication yard. As can be seen in Figure 1, the overlapping area of TC1 and TC4 was the storage area for the precast concrete products which would be used for Block 1. The precast concrete products produced in the on-site fabrication yard were transferred to the storage area for installation. Such transferring activities were not adding value to the erection process when examined by the lean thinking.

It is proposed that TC1 be re-allocated so that direct usage of the precast concrete products could be achieved. The re-allocation of TC1 is shown in Figure 2. It should be noted that direct usage of the precast concrete products produced in the on-site fabrication yard could also be achieved by choosing a tower crane with a longer jib. However, this might increase the rental costs by using such tower cranes.

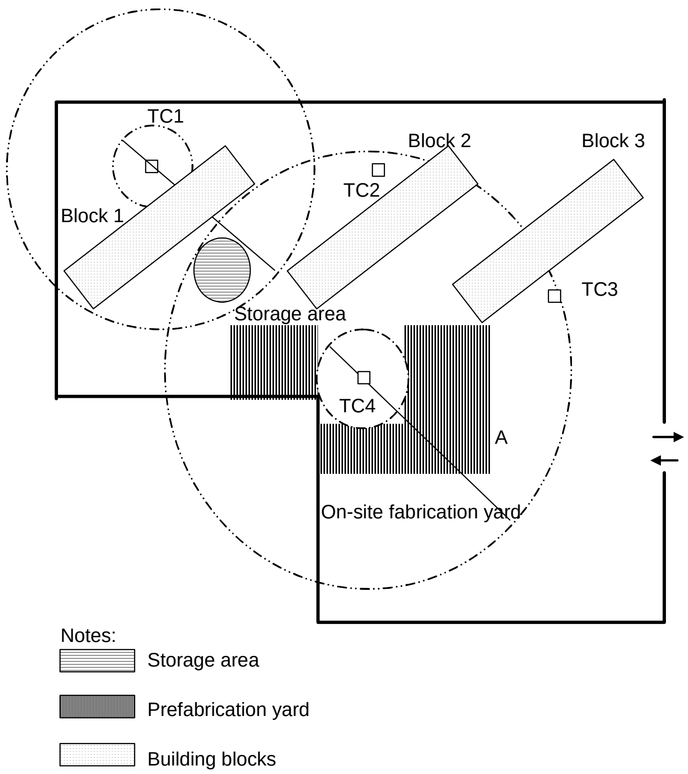

Figure 1. The site layout of the construction site

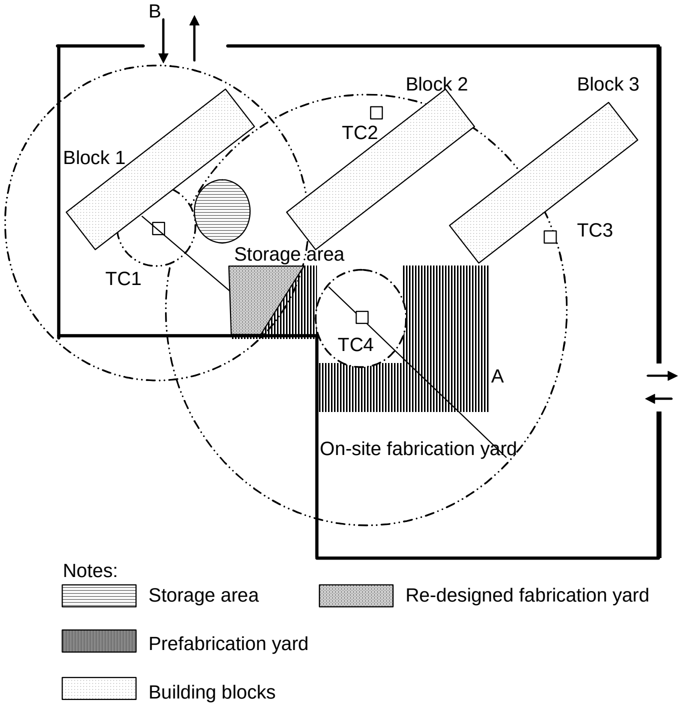

Figure 2. Re-allocating TC1 to achieve smooth work flow

Step 2 – Re-design the on-site fabrication yard. Following the re-allocation of TC1, the on-site fabrication yard should be re-designed to facilitate immediate usage, which is referred in lean as the pull system. As illustrated in Figure 3, under normal circumstances, the production of the precast concrete products were organized in such a way that each type of products was produced in a separate section of the site layout. This was the strategy that Contractor A adopted for on-site. However, it is proposed that another grouping strategy should be adopted to achieve low inventory and smooth work flow, as shown in Figure 4.

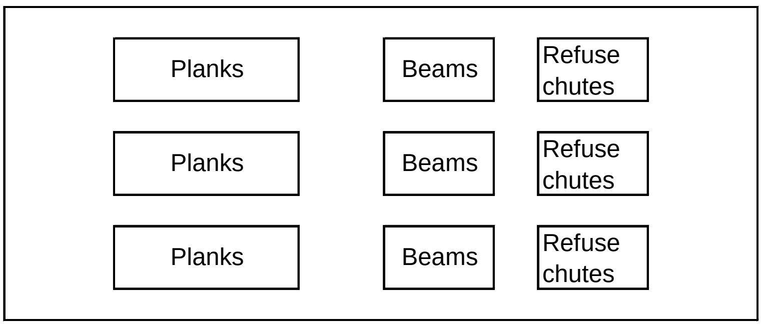

Figure 3. Previous on-site fabrication yard

The strategy adopted in Figure 4 was to group the precast concrete products which were used in Building Block 1 into an area so that TC1 could conduct the installation activities once the precast concrete products were produced. Unlike the traditional production arrangement, this strategy would enable the contractor to conduct immediate installation without transferring activities and inventory to make the construction activities flow without interruptions.

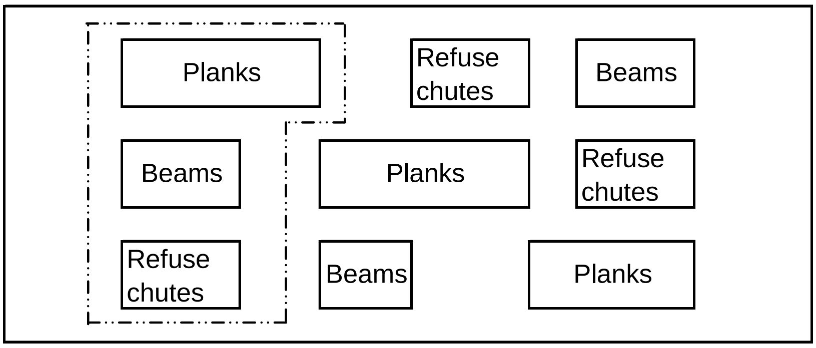

Figure 4. Re-designed on-site fabrication yard

Step 3 – Create another entrance at location B, as shown in Figure 2. Another entrance should be opened in location B to facilitate the delivery of other precast concrete products (columns, window frames and staircases) to Building Block 1. These precast concrete products would therefore not be transferred by TC4 to the storage area for installation. Immediate installation could be arranged for Building Block 1 if entrance B was created.

Step 4 – Grouping the precast concrete products used for Building Block 2 and 3. Similar to the re-design for Building Block 1, the production of the precast concrete products for Building Block 2 and 3 (using TC2 and TC3 respectively) could be re-arranged. Such arrangement would make the precast concrete products available for installation once produced.

JIT delivery

The delivery of the precast concrete columns from the precast concrete factories to the construction site was operated by a subcontractor. An “all-in-one” price was adopted so that Contractor A could focus on installation and other construction activities. The quantities required in the following one or two days were carefully estimated. Based on the estimated quantities, the precast concrete columns were delivered to the construction site, unloaded at the storage area and installed when needed. Contractor A was not facing demand fluctuations. According to the project manager interviewed, although there would be small changes in the quantities of the precast concrete columns from day to day, such changes were very small and a stable erection schedule could be anticipated. It seems that the JIT delivery system (Tommelein and Li, 1999) can be applied in this project because of the stable erection schedule and the satisfactory performance of subcontractors. However, following the screening procedure, Contractor A appeared to face several problems in delivery management from a lean perspective. The “all-in-one” price was adopted for the precast concrete columns used in this project. As the transportation job was subcontracted to the precasters, Contractor A might lose control of the delivery time, causing interruptions to the preparation for the arrival of the precast concrete columns. As observed in the construction site, the delivery time caused many interruptions to the erection process. The delivery time of ready mix concrete (for on-site fabrication) and the delivery time of the precast concrete columns overlapped, causing the delivery vehicles to idle on the road for 5 minutes to 30 minutes. During the site investigation, these idling vehicles often happened and generated a significant amount of carbon emissions. Tommelein and Li (1999) proposed that a two-order system, which was also referred to as the JIT delivery, should be adopted to manage the delivery. In the advance order, approximate quantities and the delivery time were defined to reserve site capacities on the delivery day. A few days prior to the actual delivery date, confirmation order (or release order) must be sent to the contract to confirm the previously agreed delivery, including quantity, delivery date and time. Modifications could therefore be made to previous advance order. However, it should be noted that such modifications should be kept to minimum as deviation from planned schedule would increase cycle time and might interrupt the delivery process.

Installation procedure

As observed in Contractor A, a smooth work flow was not always followed. There were a few interruptions to the work flow which were caused by apathetic employees. These interruptions included:

- When transferring the precast concrete column from the pick-up point (location A as shown in Figure 1) to the storage area, the precast concrete column is suspended for almost 5 minutes when the employees attempted to make a place for the column in the storage area. This non-value adding activity happened every day in the four conservative days of observations.
- Due to the on-site fabrication of other precast concrete products, TC4 was heavily used. The use of TC4 did not follow a smooth work flow. When TC4 was arranged to pick up the precast concrete column at the pick-up point (location A), the crane operator was told to conduct the demoulding work instead. Such unnecessary swing of the jib would cause an increase in the level of carbon emissions.
- The position where the precast concrete column should be installed was marked with a clear line in the construction site. Erection accuracy should be checked before releasing the precast concrete column. However, as observed in Contractor A, some steps of the erection accuracy checks were conducted after the release of the precast concrete column. For example, a ruler was used to check whether the alignment of the precast concrete column relative to the marked point was straight. This accuracy check was conducted after the precast concrete column was released from the tower crane, which might cause double-handling when the accuracy check was not satisfactory.

Discussions

Green building materials (green concrete in this case) was slightly higher in price than normal building materials. Incentives should therefore be provided to encourage contractors, developers and clients to use green building materials to achieve green building certifications. Other than the CDM Documentation Grant and the carbon trading funds in Singapore, the GM GFA (Green Mark Gross Floor Area) Incentive Scheme has been provided for contractors, developers and clients who aim to develop buildings that attain higher tier Green Mark ratings. This scheme would grant additional floor area over and above the Master Plan Gross Plot Ratio (GPR) control (BCA, 2010).

As stated previously, facilities managers and employees who are working closely with equipment should have the greatest potential to reduce carbon emissions in construction sites. However, the competence of the facilities managers and employees of Contractor A could be improved, as observed in the construction site. Many non-value adding activities happened in the construction sites because the employees lacked a vision of smooth work flow. All preparatory work should be completed before the installation work can start. For example, when observing the delivery of finishing sands (which are contained in fabric bags) to the construction site, it is found that the wooden supports for such bags (so that these bags of sands can be transferred using forklifts) were provided while the delivery vehicle was kept idling. In addition, during one day of the site observation when there was a heavy rain, the air compressor was left running for almost one hour until the rain stopped. Although these non-value adding activities were not within the scope of this study, this does not mean that these activities were not important. When a typical 2HP air compressor was left idling for one hour, almost 0.8kg of CO_2 will be emitted (based on the emission factor for electricity generation of Singapore). As more project management and environmental management practices and processes will be considered in green building rating systems (Wu and Low, 2010), such non-value adding activities may affect the certification of the construction project. It is therefore necessary for the contractors to appropriately train the employees on the knowledge of lean to eliminate the on-site non-value adding activities.

In this study, equipment idling was a serious problem. This might be caused by using on-site fabrication with off-site fabrication. While on-site fabrication could usually bring economic savings, the site arrangements and transportation arrangements should be more carefully prepared than using off-site fabrication alone. In this case, both site arrangements and transportation arrangements could be improved to prevent equipment idling to reduce carbon emissions. In fact, if equipment idling was listed as one of the consideration in BCA Green Mark certification, this project might fail in this criterion. The JIT delivery can be used in precast concrete projects to reduce idling, especially the delivery performance of the suppliers in this case study is satisfactory. One major concern in using JIT delivery is that whether increased number of deliveries caused by small-lot will raise the level of carbon emissions. However, it should be noted that in delivering precast concrete products, there are usually several pieces of products (such as six columns in this case) arranged per delivery. It is extremely unlikely that the construction project will require less than six columns per day. Small-lot deliveries therefore do not increase the number of deliveries in precast concrete projects.

Unlike the production processes in the precast concrete factories, the erection processes in construction sites were very straightforward. Immediate installation could be arranged if a JIT delivery system was organized. The project manager stated that the delivery performance of the precaster was satisfactory, which seems that a JIT application can be used. It is therefore proposed that a Value Stream Mapping (VSM) process should be conducted to take steps to eliminate the non-value adding activities. In addition, the trainings and developments relating to the knowledge of lean thinking should be improved. Two types of team should be appropriately trained by the contractors. The first type of team is the Kaizen team, who will conduct visual observations in the construction sites. By conducting the VSM process and using basic tracking tools, non-value adding activities can be identified by the Kaizen team, based on which quick fix can be executed. The second type of team is the Lean team, who will conduct a higher level of VSM with value added focus. While the Kaizen team usually conducts short-term visit in the construction sites, the Lean team should base the VSM process on a long-term basis. Continuous improvement plan provided by the Lean team can be used on future projects to achieve better environmental performance.

However, it should be noted that there are many lean techniques, such as just-in-time (JIT) and total quality control (TQC), that the degree of leanness should be clearly indicated in order for contractors to conduct the benchmarking process. Wu and Low (2011) proposed that a lean value should be assigned to the precast concrete products along with the carbon emissions value under the Singapore Green Labelling Scheme (SGLS) initiated by the Singapore Environment Council (SEC, 2011). Similarly, a lean value can be obtained in the installation cycle to indicate the degree of the leanness of the installation process. Such lean value seems appropriate when assessing carbon emissions. However, the applicability of the lean value to other environmental aspects should be examined before recommendations can be made.

Conclusions

The lean concept can be applied in the construction sites that use precast concrete products to achieve some green benefits, such as low carbon emissions, low wastage and increased efficiency. The lean principles that can be applied to achieve low carbon emissions include grouping technology, JIT delivery and uninterrupted work flow. The site layout of the construction site can be improved to simplify the work flow. The delivery of precast concrete products can be rearranged to support immediate installation, especially when the performance of suppliers is satisfactory in this case study. In contradiction with previous research that the JIT sourcing may increase carbon emissions by introducing more deliveries because of its small lot nature, this study shows that this is not true in the precast concrete industry. In this case study, six precast concrete columns are arranged for each delivery and it is highly unlikely that a project will use less than six precast concrete columns each day. Trainings relating to the concept of lean should be provided to employees. The VSM process can therefore be conducted by these employees to identify the non-value adding activities in the construction sites to improve the environmental performance. The lean concept advocates that simplicity is achieved in the installation cycle, from where the green benefits can be obtained.

References

American Institute of Architects, 2007. *Architects and Climate Change*. [Online] Available at: http://www.aia.org [Accessed 20 Feb 2008].

Bae, J.W. and Kim, Y.W., 2007. Sustainable value on construction project and application of lean construction methods. In Pasquire, C. and Tzortzopoulos, P., eds. *Proceedings of IGLC-15*. Michigan, USA, 2007: 312-321.

BCA, 2010. *Green mark gross floor area (GM GFA) incentive scheme*. [Online] Available at: http://www.bca.gov.sg/greemark/gmgfa.html [Accessed 20 Mar 2011].

Brown, C.S., 2005. *The sustainable enterprise: profiting from best practice*. London: Kogan Page.

Cusumano, M.A., 1994. The Limits of Lean. *Sloan Management Review*, 35(4), pp.27-32.

Drucker, P.F., 1989. *The new realities: in government and politics, in economics and business, in society and world view*. 1st ed. New York: Harper and Row.

Ellis, G., 2004. Industrially interesting approaches to low-CO_2 cements. *Cement and Concrete Research*, 34(9), pp.1489-98.

EPA, 2003. *Lean Manufacturing and Environment*. [Online] Available at: http://www.epa.gov/lean/performance/index.htm [Accessed 14 Nov 2010].

Ferng, J. and Price, A.D.F., 2005. An exploration of the synergies between Six Sigma, total quality management, Lean construction and sustainable construction. *International Journal of Six Sigma and Competitive Advantage*, 1(2), pp.167-87.

Helper, S., Clifford, P.G. and Rozwadowski, H., 1997. *Can Green Be Lean*. A paper submitted to the Academy of Management Annual Meeting. Organizations and the Natural Environment.

Hendriks, C.A. et al., 1999. *Emission Reduction of Greenhouse Gases from the Cement Industry*. Cheltenham: International Energy Agency Greenhouse Gas RandD Programme.

Herzog, H.J., 2001. What Future for Carbon Capture and Sequestration. *Environmental Science and Technology*, 35(7), pp.148A-53A.

Howell, G.A. and Ballard, G. (1998). Implementing lean construction: understanding and action. In Formoso, C.T. (ed.), *Proceedings of IGLC-6*, 13-15 August, held at Guaruja, Brazil.

Huovila, P. and Koskela, L., 1998. Contribution of the Principles of Lean Construction to Meet the Challenges of Sustainable Development. In Formoso, C.T., ed. *Proceedings of IGLC-6*. Guaruja, Brazil, 1998.

Kaplinsky, R. and Morris, M., 2001. *A handbook for value chain research*. [Online] Available at: http://www.globalvaluechains.org/docs/vchnov01.pdf [Accessed 18 Aug 2009].

Klotz, L., Horman, M. and Bodenschatz, M., 2007. A lean modeling protocol for evaluating green project delivery. *Lean Construction Journal*, 3(1), pp.1-18.

Koskela, L., 1992. *Application of the new production philosophy to construction*. CIFE technical report#72. Stanford University.

Koskela, L., 2000. *An exploration towards a production theory and its application to construction*. Technical Research Centre of Finland: ESPOO.

Lapinski, A.R., Horman, M.J. and Riley, D.R., 2006. Lean process for sustainable project delivery. *Journal of Construction Engineering and Management*, 132(10), pp.1083-91.

Low, S.P., Liu, J.Y. and Wu, P., 2009. Sustainable facilities: Institutional compliance and the Sino-Singapore Tianjin Eco-city project, *Facilities*, 27 (9): 268-386.

Luo, Y., Riley, D. and Horman, M.J., 2005. Lean Principles for Prefabrication in Green Design-Build (GDB) Projects. In Russell, K., ed. *Proceedings of IGLC-13*. Sydney, 2005: 539-548.

Nahmens, I., 2009. From Lean to Green Construction: A Natural Extension. In Ariaratnam, S.T. and Rojas, E.M., eds. *Proceedings of the 2009 Construction Research Congress*. Seattle, 2009: 1058-1067.

Ohno, T., 1988. *Toyota Production System: Beyond Large-Scale Production*. Tokyo: Diamond, Inc.

Pelling, M., Maskrey, A., Ruiz, P. and Hall, L., 2004. *Reducing Disaster Risk: A Challenge for Development.* New York: United Nations Development Bank, Bureau for Crisis Prevention and Recovery.

Riley, D. et al., 2005. Lean and Green: the Role of Design-Build Mechanical Competencies in the Design and Construction of Green Buildings. In Tommelein, T., ed. *Proceedings of the 2005 Construction Research Congress*. San Diego, CA, 2005.

Rothenberg, S., Pil, F.K. and Maxwell, J., 2001. Lean, Green and the Quest for Superior Performance. *Journal of Production and Operations Management*, 10(3), pp.228-43.

SEC, 2011. Singapore Green Labelling Scheme. Available from: http://www.sec.org.sg/awards/greenlabel/criterion [accessed 21st Mar 2011].

SISV, 2008. *Carbon index*. [Online] Available at: http://www.sisv.org.sg/publications/articles [Accessed 20 March 2011].

Spence, R. and Mulligan, H., 1995. Sustainable development and the construction industry. *Habitat International*, 19(3), pp.279-99.

Stern, N., 2007. *The economics of climate change: the Stern review*. New York: Cambridge University Press.

Tang, K. and Yeoh, R., 2007. *Cut carbon, grow profits: business strategies for managing climate change and sustainability*. London: Middlesex University Press.

Tommelein, I.D. and Li, E.Y., 1999. Just-In-Time concrete delivery mapping alternatives for vertical supply chain integration. In Tommelein, I.D., ed. *Proceedings of IGLC-7*. Berkeley, CA, 1999:97-108.

Whiteley, R.C., 1991. *The customer-driven company*. Reading: Addison-Wesley.

Williams, T.M., 1993. Risk-management infrastructures. *International Project Management*, 11 (1), pp. 5-10.

Womack, J.P. and Jones, D.T., 1996. *Lean Thinking*. New York: Simon and Schuster.

Wu, P. and Low, S.P., 2010. Project management and green buildings: lessons from the rating systems. *Journal of Professional Issues in Engineering Education and Practice,* 136(2), pp.64-70.

Wu, P. and Low, S.P., 2011. Managing the embodied carbon of precast concrete columns. *Journal of Materials in Civil Engineering*. Vol. 23, No. 8, pp. 1192-1199.

Wu, P. and Low, S.P., 2011. Lean production, value chain and sustainability in precast concrete factory – a case study in Singapore. *Lean Construction Journal*. (Accepted for publication)

Yates, J.K., 2007. *Global Engineering and Construction*. Hoboken, New Jersey: John Wiley and Sons.