Lean Production Paradigms in the Housing Industry

Tariq Abdelhamid[1]

Abstract

Despite that homeownership may be at record levels today, the continuing disparities in wealth and access to financial services between economically distressed cities compared to urban and suburban communities underscores the prodigious work that remains to be accomplished. This paper focuses on an important factor in the housing equation – the construction management and production of houses. The paper presents a lean-based research agenda to improve the process of housing production. To this end, the paper begins first by presenting a brief background on lean construction concepts and principles. This is followed by a discussion of relevant research projects completed at Michigan State University. The paper concludes with ideas for future research.

Keywords: Lean Production, Lean Construction, Housing Production, Production Waste, Production Variability

Introduction

Recent statistics published by the U.S. Department of Housing and Urban Development as well as other non-profits show that in the first quarter of 2001 homeownership rates were at 67.4% and in the same year the homeownership rate for central cities reached a record high of 51.2 percent (Squires 2003). Much of the progress achieved so far in housing is attributed to the success of advocacy group efforts as well as demonstrable results and successes on the part of community development groups and associations. These efforts were undoubtedly facilitated by policy changes promulgated by Congress such as the Fair Housing Act, the Home Mortgage Disclosure Act, the Community Reinvestment Act, and the Financial Services Modernization Act (Squires 2003).

Notwithstanding that homeownership may be at record levels today, the continuing disparities in wealth and access to financial services between economically distressed cities compared to urban and suburban communities underscores the prodigious work that remains to be accomplished.

This paper presents a lean-based research agenda to better one of the factors in the housing equation – the construction management and production of housing projects. To this end, the paper begins first by presenting a background on lean construction concepts and principles. Relevant research projects conducted at Michigan State University are also presented. The paper concludes with ideas for future research.

From Lean Production to lean construction

[1] Assistant Professor, 207 Farrall Hal; Construction Management Program, Michigan State University, East Lansing, MI 48824-1323 Tel:(517)432-6188; Fax:(517)355-7711; E-mail: tabdelha@msu.edu

Around the early 1950s, under the leadership of the brilliant engineer Taichi Ohno, lean production principles were developed and successfully implemented by Toyota Motor Company. Toyota strived to work towards the ideal of 100% value-added work with zero (or minimum) waste. Popularized by the book *The Machine That Changed The World* (Womack et al. 1990), these lean principles are being increasingly employed in many other industrial sectors. Since 1992, ushered in by Koskela's seminal report (Koskela 1992), the adoption and adaptation of lean production concepts in the construction industry has been ongoing.

Koskela (1992) presented a production management paradigm where production was conceptualized in three complementary ways, namely, as transformation, as flow, and as value generation – also termed the TFV theory of production. This tripartite view of production has lead to the birth of Lean Construction as a discipline that subsumes the transformation-dominated contemporary construction management (Koskela and Howell 2002, Berteslen and Koskela 2002).

Lean Construction has escaped canonical definition mainly because Lean principles defy easy characterization. A frequently referenced definition is that of the Lean Construction Institute (LCI) according to which lean construction is a production management-based philosophy emphasizing the need to simultaneously design a facility and its production process while minimizing waste and maximizing value to owners throughout the project phases [including the post-construction phase] by improving performance at the total project level, using a conformance-based vs. a deviation-based performance control strategy, and improving the reliability of work flow among project participants (Howell 1999). Stated differently, lean construction forces the explicit consideration of work flow and value management in addition to the traditional construction management focus on transformation management, i.e., transferring materials into building objects. Adding workflow and value management is integral to the successful delivery of capital projects.

A profound implication of the TFV concept of production is that it changes the definition of Construction Management from "The judicious allocation of resources to complete a project at budget, on time, and at desired quality" (Clough and Sears 1994) to the "The judicious allocation of resources to transform inputs to outputs while maximizing flow and value to the customer" (Abdelhamid 2003).

Perhaps one of the better ways to capture the governing thought process in lean production is to contrast the conventional pricing method for products to the one used in lean production. The conventional cost principle is depicted in Figure 1 where the price of a product is determined based on finding its production cost and then adding profit to it. Under this approach, in the event of an increase in production costs, maintain the same profit margins are only possible by in increase in selling price. In fact, even increasing profits is achieved only through an increase in selling price.

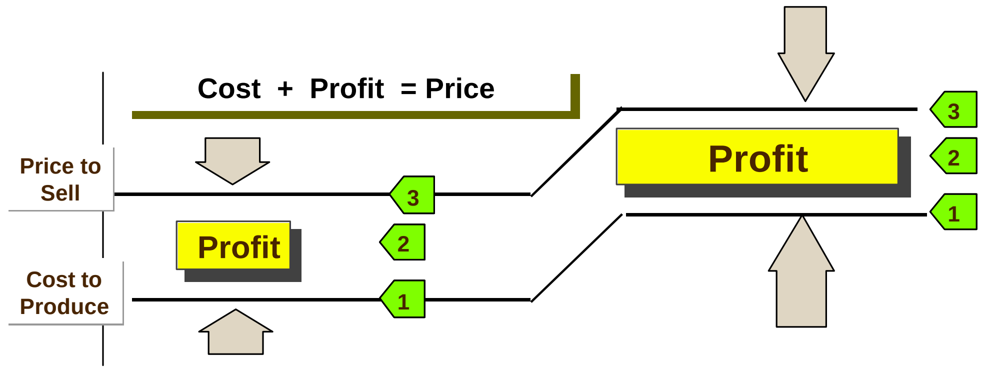

Figure 1. Conventional Cost Principle

In contrast to this method, lean production companies use a non-cost principle as shown in Figure 2. Under this method, based on governing market conditions and other factors, the price a customer is willing to pay is determined independent of the production cost. Profit is then determined by subtracting the cost of production from the selling price. Hence, in this system, the only way to maintain or increase profits is to lower the cost of production. Consequently, reducing the cost of production in lean systems has become a goal of paramount importance and a measure of the effectiveness and efficiency of the production system.

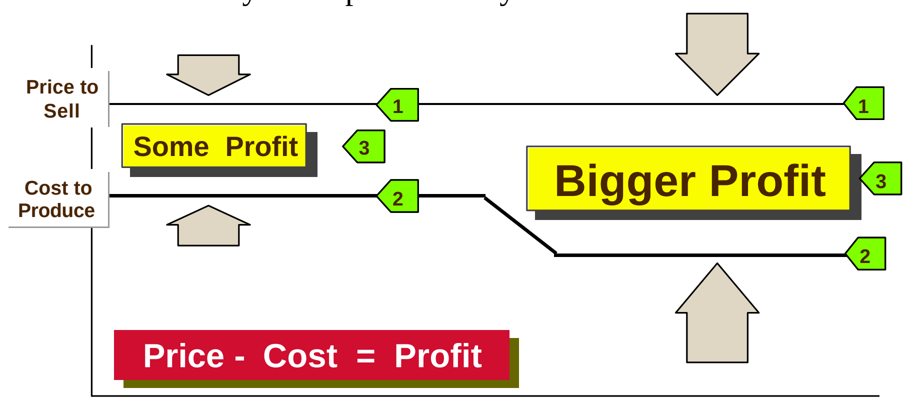

Figure 2. Non-cost Principle

Reducing the cost of production in lean systems was facilitated by viewing production as flow of materials and information, which in turn has led to the principle of waste (muda)[2] elimination. In fact, master Ohno considered waste as his –and Toyota's– number one enemy (Howell 1999). He named seven sources of waste that plague production processes and tirelessly worked on eliminating them (Table 1 provides examples of these seven waste sources). The basic tenant was that identifying the root causes of the forms of waste listed in Table 1 and developing process improvement initiatives to eliminate them will almost certainly result in better production workflow, which in turn leads to a reduction in production costs and an increase in throughput (Womack and Jones 1996). This same maxim is emphasized in the lean construction literature (Everett 1992, Koskela 1993, Howell and Ballard 1994, and Howell 1999).

[2] Muda is Japanese for waste

Table 1. The 7 forms of waste (Mastroianni and Abdelhamid 2003)

	Form of Waste	Example
1	**Over-Production:** Producing over the customer requirements, producing unnecessary materials/products	Producing more pipe spools than required
2	**Inventory:** Holding or purchasing unnecessary raw supplies, work-in-progress inventory, finishing goods	Stockpiling too much dry wall in area well before it is needed and in the way of other trades
3	**Transportation:** Multiple handling, delay in material handling, unnecessary handling	Locating materials to far from the point of installation
4	**Waiting:** Time delays, idle time	Crew B waiting for an activity to be completed as promised by Crew A
5	**Motion:** Actions of people or equipment that do not add value to the product	Double and triple handling of material when planning could have reduced it to one move
6	**Over Processing:** Unnecessary processing steps or work elements	Rubbing a concrete foundation wall to well when it will be backfilled or covered
7	**Correction:** Producing a part that is scrapped or requires rework /procedures	Punchlist items or items of work that are deficient and do not meet requirements which require rework

An associated principle with waste removal is variability reduction (Berteslen and Koskela 2002). While variability (mura)[3] has a myriad of causes it manifests itself mainly in the form of poor workflow reliability between production processes. The damaging and corrupting[4] effects of variability on dependent processes has been addressed in Tommelein et al. (1999), Tommelein 2000, and Howell et al. 2001. Schonberger (1986) emphatically states that "variability is the universal enemy" and that reducing variability increases predictability and reduces cycle times. Koskela (1992) adds that reducing process variability will also increase customer satisfaction and decreases the volume of non value-adding activities. Additional discussion on the topic can be found in Goldratt (1992), and Hopp and Spearman (2000).

In the construction industry, sources of variability include late delivery of material and equipment, design errors, change orders, equipment breakdowns, tool malfunctions, improper crew utilization, labor strikes, environmental effects, poorly designed production systems. When left uncontrolled, these factors create havoc on any construction project resulting in either barely meeting the numbers or suffering devastating losses.

Howell and Ballard (1994) state that achieving reliable workflow is possible when sources of variability are controlled. Under a lean paradigm, the effects of variability on workflow reliability are mitigated through the use of surge piles, plan buffers, and/or flexible capacity (Ballard and Howell 1998). Surge piles could be in the form of raw and/or processed material. Plan buffers refer mainly to having a backlog of work for crews. Flexible capacity refers to intentional underutilization of a crew or the ability of using a resource in multiple ways by having cross-trained workers. Other examples of flexible capacity can be found in Hopp and Spearman (2000). These three approaches are attempts to combat the effects of variability and not to eliminate variability altogether. In current practice, surge piles or perhaps excess inventory

[3] Mura is Japanese for variability
[4] Hopp and Spearman (2000) used this term in addressing the effects of variability

prevails over the other two approaches. Practitioners also use efficiency factors or the 45-minute productive hour to account for the effects of variability on crew productivity.

The elimination or, more realistically, the reduction of variability requires the identification and removal of the root causes of variability. Koskela (1992) mentions that implementing standard procedures is one strategy to reduce variability in conversion and flow processes. He also mentions Shingo's "poka-yoke" or mistake-proofing devices and techniques as another strategy to reduce variability. Koskela (1992) also states that statisticians have been battling variability through statistical quality control theory and techniques. This latter strategy has been reinvigorated in the industrial and business sectors through the Motorola-developed Six Sigma approach (Abdelhamid 2003). Abdelhamid and Everett (2002) also argue that occupational accidents are as wasteful and non-value adding events in production systems as other wasteful and non-value adding events. It follows then that safeguarding construction workers from occupational hazards, whether arising from traumatic, ergonomic, and/or exposure accidents, is part and parcel of the lean construction ideal of waste elimination.

One of the important principles under a lean production paradigm is termed lean assembly. This refers to simplifying the process of assembly through industrialization, modularizations, standardization, and continuous flow processes. To aid in this simplification process, the assembly or production operations are placed under scrutiny (e.g., using Kaizen events) and improvements are suggested (e.g., using the 5S process) to reduce waste that manifests itself as overproduction, rework, and long cycle times. It is typical for such reviews to identify opportunities for reducing the number of operations/steps required for production, thus leading to the reduction of waste and increase in quality. Though most likely serendipitous, a welcome by-product of these efforts is the improvement of safety and ergonomics related issues in the production process. The mere reduction of operations required for a production process means that there are less chances for traumatic, ergonomics, and exposure injuries to occur. This follows from the same logic that the fewer the number of operations, the higher the quality of the product because there are less chances of making errors.

An increasing number of construction academics and professionals have been storming the ramparts of conventional construction management in an effort to deliver better value to owners while making real profits. As a result, lean-based tools have emerged and have been successfully applied to simple and complex construction projects. One of the lean-based tools that have emerged and have been successfully applied to control workflow unreliability on simple and complex construction projects is the Last Planner System® (LPS®) (Ballard and Howell 1994a). The LPS® promotes production control as opposed to the dominant project control paradigm under conventional construction management. The system empowers front-line planners, the Last Planners, to schedule day-to-day production assignments according to the prevailing conditions on the site (Ballard and Howell 1998). Production assignments are established based on the ability to perform them and not only based on what "should" be done. To measure the effectiveness of the production system to carryout assignments (commitments), the number of completed assignments is expressed as a ratio of the total number of assignments committed in a given week. This ratio is known as the Percent Plan Completed or PPC which is a metric reflecting the effectiveness of production planning and the reliability of workflow from one trade to another (Ballard and Howell 1994b, Howell and Ballard 1994, Ballard et al. 1996).

Using the LPS® as a planning tool uncovers a myriad of constraints that threaten the execution of assignments as well as production progress. By removing these constraints, Last Planners are more confident in making and keeping their commitments. Notwithstanding the removal of these constraints, events are bound to happen that thwart even the best prepared, and, hence, prevent the honoring of commitments made. When used as a production control tool, i.e., tracking the PPC metric, the Last Planner System allows management of such circumstances. Production process improvement initiatives are identified when 100% PPC is not achieved. A detailed explanation of the LPS® is beyond the scope of this paper and can be found in Ballard (2000).

Relevant Research Projects

The author has been performing research in the area of Lean Construction since November of 2000. The following is a partial listing of the completed research projects led by the author at Michigan State University which involved the implementation of lean production principles in the housing industry include the following:

?? On-going: Principal Investigator – Predicting Relative Workload During Physically Demanding Work – Funding agency: National Institute of Occupational Safety and Health (2002-2004).

?? Completed: Co-Principal Investigator – Manufactured Housing Construction Quality Guidelines – Funding agency: Consumers Union Southwest Regional Office – Manufactured Housing Research Initiative (2002-2003) -.

?? Completed: ✍ Performance Assessment During Manufactured Housing Production Operations Using Lean Production Principles (2001 – 2002).

?? Completed: Assessment of Manufactured Housing Construction Quality: A Consumer Perspective (2002 – 2003).

?? Completed: Identification of the Safety and Health Competencies for Structural Steel Workers in Construction (2002-2003).

Currently, the author serves as the chair of the Lean Construction Institute Academic Forum and is the editor of the newly launched Lean Construction Journal. The following are selected relevant lean-related publications:

1. Abdelhamid, T. S., and Everett, J. G. (2002). "Physiological demands During Construction Work". *Journal of Construction Engineering and Management*, ASCE, 128(5), 427-437.
2. Abdelhamid, T. S., and Everett, J. G. (2002). "Physical demands of construction work: A source of workflow unreliability". *Proceedings of the 10th Annual Conference for Lean Construction*, 6-8 August 2002, Gramado, Brazil, 75-86.
3. Abdelhamid, T. S. (2003). "Six-Sigma in Lean Construction Systems: Opportunities and Challenges". *Proceedings of the 11th Annual Conference for Lean Construction,* 22-24 July 2003, Blacksburg, Virginia, 65-83.
4. Abdelhamid, T. S., Patel, B., Howell, G. A., and Mitropoulos, P. (2003). "Signal Detection Theory: Enabling Work Near The Edge". *Proceedings of the 11th Annual Conference for Lean Construction*, 22-24 July 2003, Blacksburg, Virginia, 243-256.

5. Chitla, V. K., and Abdelhamid, T. S. (2003). "Comparing Process Improvement Initiatives Based On Percent Plan Complete And Labor Utilization Factors". *Proceedings of the 11th Annual Conference for Lean Construction*, 22-24 July 2003, Blacksburg, Virginia, 118-131.
6. Howell, G. A., Ballard, G., Abdelhamid, T. S., and Mitropoulos, P. (2003). "Rethinking safety: Learning to work near the edge". *Proceedings of the 2003 ASCE Construction Research Congress,* 19-21 March 2003, Honolulu, Hawaii.

Future research

The sub-areas identified under the focus area of Construction Management and Production are prime candidates for research using lean production principles. The sub-areas of interest to the author are listed below with suggested future research projects. It is important to note that the word housing, unless otherwise stated, refers to all types of housing, i.e., site-built and factory-built housing.

- Project Planning and Control
    - Assessment of Site-Built Housing Production Planning Performance Using Lean Construction Principles. In this project, the process of planning operations for conventional (site-built) residential construction will be examined using the Last Planner process and Six-Sigma Techniques. This will help in identifying opportunities for improving workflow and productivity of individual activities.

- Site based Construction Processes
    - Construction Waste:
        - Identification of Production Waste During Housing Projects: Production activities will be observed on construction sites to identify and catalogue the prevalence of the seven lean-based waste factors. Opportunities for improvement will be identified and implemented using Kaizen and Kaikaku processes.
    - Construction Ergonomics:
        - Performance Improvement During Housing Production Using Occupational Ergonomics. Work physiology research indicates that physically demanding work leads to physical fatigue which in turn leads to decreased productivity and motivation, inattentiveness, poor judgment, poor quality work, job dissatisfaction, accidents, and injuries. Considering that these effects are non-value adding to construction projects, the proposed research will investigate the physical demands of operations in housing operations using current ergonomic principles. The research will also address ways to increase performance by changing current work methods and practices, including investment in more automated tools and equipment; providing appropriate work-rest cycles; or even adjusting expectations of what workers can reasonably be expected to accomplish. These and many other examples of administrative and engineering interventions to reduce physical demands and fatigue would provide endless opportunities to improve construction work performed in fabricated housing plants.

- Supply Chain Management

?? Viability of Lean Manufacturing Just-In-Time Material Procurement Practices in the Housing Industry. The main aim of this proposed research is to investigate the viability of adopting Just-In-Time (JIT) material procurement practices in the housing industry. This aspect of housing has not received much attention in the literature. The research should address the following issues:
   - What are the attributes and business models that contribute to the success of JIT systems in the Manufacturing industry?
   - What are the current material procurement practices and business models in the Housing industry?
   - Is it logistically possible and economically feasible to re-structure the supply chain serving the Housing industry to a JIT system?

Conclusion

This paper presented an overview of lean production and the evolution of lean construction. The paper then presented relevant housing research projects conducted at Michigan State University. Future research ideas in the focus area of Construction Management and Production have been discussed.

Undoubtedly, any attempt or effort to address the crisis in housing in the United States, or even worldwide, must consider the full range of issues affecting the creation, development, and maintenance of safe and sustainable housing communities. While the design and construction aspects of a house are major determinants in the overall short and long-term cost of a house, education, poverty, racism, disinvestment, lack of employment, and breakdown of the social fabric are all factors that contribute to the housing crisis. Financial institutions, builders, investors, developers, local neighborhood organizations, elected officials, and academics must coordinate their efforts in addressing the housing problem such that global solution to the housing problem may be found instead of 'local optimums'.

References

Abdelhamid, T. S., and Everett, J. G. (2002). "Physical demands of construction work: A source of workflow unreliability". *Proceedings of the 10th Conference of the International Group for Lean Construction*, Gramado, Brazil, August 6-8.

Ballard, G (2000). *The Last Planner System of Production Control.* PhD dissertation, University of Birmingham, UK.

Ballard, G. (1997). "Improving Work Flow Reliability". *Proceedings of the 7th Annual Conference of International Group of Lean Construction*, Berkeley, CA, July 26-28, 1999.

Ballard, G. and Howell, G. (1994a). "Implementing Lean Construction: Stabilizing Work Flow." *Proceedings of the 2nd Annual Meeting of the International Group for Lean Construction*, Santiago, Chile.

Ballard, G. and Howell, G. (1994b). "Implementing Lean Construction: Improving Performance Behind the Shield." *Proceedings of the 2nd Annual Meeting of the International Group for Lean Construction*, Santiago, Chile.

Ballard, G. and Howell, G. (1998). "Shielding Production: Essential Step in Production Control". *Journal of Construction Engineering and Management*, Vol. 124, No. 1, pp. 11 - 17.

Ballard, G., Howell, G., and Casten, M. (1996). "PARC: A Case Study". *Proceedings of the 4th Annual Conference on Lean Construction*, Birmingham, England.

Bertselen, S. and Koskela, L. (2002). "Managing The Three Aspects Of Production In Construction." *Proceedings of the 10th Conference of the International Group for Lean Construction*, Gramado, Brazil, August 6-8.

Clough, R. H. and Sears, G. A. (1994). *Construction Contracting*. Wiley, New York, NY.

Everett, J. G. (1992). Let's pass on Mass Production. *Construction Business Review* (CBR), 2(2), 13-14.

Goldratt, E. (1992). *The Goal*. North River Press, Great Barrington, MA.

Hopp, W. J., and Spearman, M. L. (2000). *Factory Physics*. McGraw-Hill, New York.

Howell, G. (1999). What Is Lean Construction. *Proceedings of the 7th Conference of the International Group for Lean Construction*, Berkeley, California, USA, 26-28 July 1999.

Howell, G. and Ballard, G. (1994). "Lean production theory: Moving beyond 'Can-Do'". *Proceedings of the 2nd Annual Conference of International Group of Lean Construction*, 1994.

Howell, G., Ballard, G. and Hall, J. (2001). "Capacity Utilization And Wait Time: A Primer For Construction". *Proceedings of the 9th Annual Meeting of the International Group for Lean Construction*, Santiago, Chile.

Koskela, L. (1992). "Application of the New Production Philosophy to Construction". *Technical Report # 72*, Center for Integrated Facility Engineering, Department of Civil Engineering, Stanford University, CA.

Koskela, L. (1993). Lean production in construction. *Proceedings of the 10th ISARC*, Houston, Texas, May 24-26, 47-54.

Koskela, L. and Howell, G. A. (2002). "The underlying theory of project management is obsolete". *Proceedings of the PMI Research Conference*, Project Management Institute, 293-302.

Schonberger, R. J. (1986). *World Class Manufacturing*. The Free Press, New York.

Squires, G. D. (2003). "No Progress Without Protest". *Shelterforce*, NHI, 128, March/April.

Tommelein, I. D. (2000). "Impact of Variability and Uncertainty on Product and Process Development". *Proceedings of Construction Congress VI, American Society of Civil Engineers*, 20-22 February 2000, Orlando, Florida.

Tommelein, I.D., Riley, D.R., and Howell G.A. (1999). "Parade Game: Work Flow Variability vs Succeeding Trade Performance". *Journal of Construction Engineering and Management*, ASCE, New York, NY, 125(1).

Womack, J. P., Jones, D.T., and Roos, D. (1990). *The Machine That Changed the World: The Story of Lean Production.* MacMillan Publishing, New York, NY.

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