IDENTIFYING LEAN CONSTRUCTION CATEGORIES OF PRACTICES IN IGLC PROCEEDINGS

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ABTRACT

The International Group of Lean Construction (IGLC) Annual Conferences have become an important source of both theoretical developments and reports of practical applications concerned with the adaptation of lean production ideas into construction. This paper presents an analysis of the lean practices that have been discussed in IGLC conference papers. It used as a starting point an analysis and classification of 3,139 keywords from 685 papers published between 1993 and 2010. A set of practices were identified and classified in categories. More than 50% of the papers were focused on four categories: production planning and control (18.4%), product development (16.4%), logistics and supply chain management (9.7%), and human resources (9.1%). Moreover, the study pointed out that some important lean construction practices have not been emphasized in the papers, such as those related to quality control, standardization and pull production.

KEYWORDS: Lean Construction practices, bibliometry, IGLC

INTRODUCTION

While the principles of lean construction (LC) defined by Koskela (1992, 2000) are similar to the principles of lean production (LP) (Womack et al. 1990; Liker 2004), the similarities are not as evident when the practices emphasized by LP and LC are taken into account (Salem et al. 2006). In this paper, LC practices are defined as management routines, based on LC principles, implemented with some degree of standardization and success on construction sites. The practices must be observable and measurable in terms of efficiency and effectiveness. Categories of LC practices are labels allocated to a set of practices that share similar goals.

On the one hand, a set of LP practices is used in a relatively uniform way in manufacturing industry, such as *kanbans* and quick setups. On the other hand, the identification of typical LC practices is not so straightforward. A noteworthy exception is the Last Planner® system of production planning and control, which has been widely recognized as a mean to operationalize the LC principles (Ballard 2000).

The lack of clear practices to implement LC creates difficulties, such as those of: (a) assessing to what extent the industry, as a whole, and each company in particular, is advancing towards a lean system; and (b) supporting companies that wish to adopt LC as a business philosophy. In fact, it is well-known that LP implementation involves the absorption of lean principles by the organizational culture and that the application of practices does not guarantee the use of the principles (Spear and

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Bowen 1999). Nevertheless, this absorption is a slow and gradual process, which is facilitated by the introduction of practices (Mann 2005).

In this context, this paper seeks to identify categories of practices that can be associated with LC as well fields that can be improved in construction industry. Such identification was based mostly on analyzing the papers published in IGLC proceedings, although key studies published elsewhere have also been consulted. The analysis of the IGLC papers was the subject of earlier work by Alves and Tsao (2007), who investigated the meaning of LC and identified what the main topics researched in the LC community were.

Another literature review of IGLC papers was conducted by Pasquire and Connor (2011), who tested the hypothesis that the references used in the papers consisted mainly of material developed in the group itself. The results were not conclusive, to the extent that strong evidence was found to support both the hypothesis that the IGLC group has been fairly endogenous and to support the hypothesis that construction theory in the IGLC has drawn on other disciplines as well.

RESEARCH METHOD

This study was conducted in four stages. Stage 1 consisted of a literature review focused on the classical references of LP (Ohno 1997; Shingo 1989; Womack et al 1990; Spear and Bowen 1999; Liker 2004) and LC (Ballard and Howell 1998a, 1998b; Koskela 1992, 2000). Based on this, categories of practices that could be applicable to LC were identified. Stage 2 included cataloguing all the keywords mentioned in the IGLC papers between 1993 (the first event) and 2010 (the penultimate event). The sample includes 729 papers with 672 with keywords. A database compiled information about each paper, including the following categories: the theme in which the paper was classified in the proceedings, the title, the abstract and keywords. In total, 3,139 keywords were worked on. The identical keywords were grouped, which resulted in 1,507 distinct keywords being identified. These in turn were grouped by similarity in meaning, resulting in 67 keyword categories. 818 (26.1%) keywords were considered unrelated to any practice. Examples of such keywords are: alliance, engineering review, formula, justice and theory. Stage 3 included associating groups of keywords with categories of practices. Thus, it was possible to quantify the number of keywords related to each category of practice. Stage 4 consisted of analyzing the results, by discussing the categories of practices most emphasized by IGLC.

RESULTS AND DISCUSSION

Identifying the categories of LP practices applicable to construction: Tables 1 and 2 show the categories of lean practices applicable to construction, identified based on the literature. LP literature mentions two categories of practices that were not identified in the analysis of the keywords of the IGLC material: quick setups and total productive maintenance. In contrast, LC literature has paid attention to safety and sustainability, which were not emphasized by the LP literature.

Previous LC studies on each categories of practice (Figure 1): The predominance of keywords linked to production planning and control (18,4% of the total) results from widespread use of the Last Planner® system. The keyword Last Planner® was the most cited one (4.0% of all keywords; 54 papers). Of course, although this keyword has been associated with the category of practice production planning and

Table 1: Categories of Practices

Categories of practices	Description	LP References	LC References
Human Resources, Multifunctionality and Job autonomy	Adding value to human resources in the productive sector. Training , team development, motivation, salary policies, behavioral analysis. Multi-functionality and job autonomy aspects are defined by LP as a necessity to meet fluctuations in the product demand.	Liker (2004)	Alarcón (1995), Koskela (1992), Salem et al., (2006), Ballard and Howell (1998b)
Continuous Improvement	Problems identification in the process, groups of problems discussion, implementation of activities feedback and internal benchmark development. Further more, organizations should be seen as a place for continuous learning, which identifies problems in the current scene and project future solutions (value stream mapping, PDCA),	Spear and Bowen (1999), Liker, (2004) Womack et al. (1990), Mann (2005)	Alarcón and Mardones (1998), Koskela (2000)
Standardized Work	Use of standard operation cards, measures to avoid waste in productivity and quality. Enable the identification and understanding of the deviations. As standardization is achieved, the product quality, process quality and the labor quality are increased (continuous improvement).	Spear e Bowen (1999), Shingo (1989), Womack et al. (1990).	Koskela (1992), Koskela (2000), Gallardo et al (2006)
Safety and Sustainability	The lack of safety is a major source of waste in construction. Beyond meeting mandatory requirements and legislation, it is expected from construction safety management the development of proactive measures and practices. Application of lean practices is also a way to reduce environmental damages. In reducing wastes in the processes is a way to implement sustainable features.		Cambraia et al. (2005), Salem et al. (2006), Bae and Kim (2007), Song and Liang (2011), Koskela (1992)
Pulled Production	One of the main concepts in the LP development is to schedule the production from a customer's need. For this mean some character are necessary: very reliable methods, multidisciplinary labor systems, production and logistics control (kanban), inventory and cycle times control.	Shingo (1989) , Liker (2004),	Koskela (1992), Koskela (2000), Ballard and Howell (1998a), Arbulu et al. (2003)
Visual Management and Performance Metrics	Visual management, in LP, is identify the process and verify if there is any deviation from the reference instantly. In construction the visual management operates in management of nine fields: process, performance, knowledge, inventory, maintenance, safety, quality, production and image. For the LP, examples of visual management and control are visual kanban, flow cell unit, andon, standardized work, obeya and performance metrics.	Shingo (1989), Liker (2004), Mann (2005)	Tezel et al. (2010), Alarcón et at. (1999)
Planning and Production Control	Establish methods of production distribution and control it in every step of the process, and, in the same time develop flows an understand the activities connections is essential in LP. One of the most widespread practices in construction aimed at planning and control of production activities is the Last Planner. Existence of an overall schedule, schedule of medium-term to eliminate restrictions and schedule short-term with the definition of activities by staff shall comprise the PPC in construction sites.	Womack et al. (1990), Spear and Bowen (1999), Liker (2004)	Ballard (1993), Ballard and Howell (1998b), Koskela (1999), Ballard (2000)
Layout e Flow	Storage locations optimization locations and layouts study in order to reduce transport wastes and dislocations. To observe the internal flows, how people are connected and map delivery of the product for a specific work post at the right time, involves inclusive. the PPC.	Ohno (1997), Spear and Bowen (1999)	Koskela (1992), Alves and Formoso (2000)
Quality Control	Quality in LP is inherently built into the production process. The total quality control (TQC) implies in eliminating waste caused by poor quality as it is perceived, as well as to eliminate wastes caused by physical interruption of flow due to a specific defects or a deviation of the pattern. In manufacturing, quality is directly linked to process control; in construction, it is concerned the compliance of the final product.	Womack et al. (1990), Shingo (1989), Liker (2004),	Koskela (1992), Koskela (2000), Salem et al. (2006)
Logistics and Supply Chain Management	There must be logistics management and and planning in inputs supply to achieve the just in time. The idea of LP at Toyota was to develop a long term partnership between manufacturer, reseller and buyer, the dealer engaging in the production system, and the buyer in the process of product development.	Shingo (1989), Womack et al (1990)	Vrijohef and Koskela (1999), Sterki et al. (2007)
Information Technology and Communication	Information Technology (IT) works with the production, distribution, storage, usage and safety of all information. In construction, the first uses of IT systems were applied to the flow control of the supply chain and design software. It is also necessary to develop adequate communication systems between productive teams	Liker (2004)	Rischmoller and Alarcón (2005), Atkin (1998), Koskela (2000).
Design Management and Product Development	More then establishing the premises of implementation and compatibility of different designs, the design phase needs, within the LP, capture and transcribe the value perceived by the customer into the final product. For this, are necessary the use of methods of market research, customer satisfaction analysis and feedback analysis, for example.	Womack e Jones (1997), Shingo (1989), Liker (2004)	Formoso et al. (1998), Koskela (2000), Howell et al. (2000)
Costs Control	Cost reduction has been a Toyota's goal since Taiichi Ohno began the movement wastes reduction in Japanese plants. Currently, Toyota has developed the Total Budget Control System, where monthly information are crossed to monitor the budget for all divisions of the company. In constructing measures of target cost management and continuous improvement groups were presented as a measure to reduce wastes and costs	Liker (2004), Shingo (1989)	Koskela (1992),Ballard (2006), Robert and Granja (2006)
Continuous Flow	The continuous flow implementation process has four steps independent of each other: diagnosis, creation of initial conditions, planning, and finally, the control. All these steps are directly linked to the Planning and Production Control and adaptation of tools from LP. Four concepts of LP are critical in the implementation of continuous flow, stability, interdependence, takt time and work elements.	Liker (2004), Rother and Shook (2000)	Picchi and Granja, (2004), Bulhões et al. (2005), Ballard and Howell (1998b)
Quick Setup	In LP, the quick setup system enabled the production of multiple models and served the change in consumer demand by reducing the time of setups on the assembly line. Quick setup is a characteristic that must be achieved if we are to meet the change in market demand.	Shingo (1989)	
Total Productive Maintenance	Routine and programmed maintenance for tools and equipment to prevent or identify, away from the activity, defects that may come to halt production. There should be a standard procedure for each tool,piece of equipment and function and this should be followed on a daily basis. In civil construction works carried out in some industrial sectors, procedures such as good safety at work practices are used.	Black (2007),	

control, its use has affected a number of other categories of practices, such as design development, supply chain management, and involvement and commitment of the workforce (Sterki et al. 2007, Ballard 1997, Ballard 2000; Sacks and Harel 2006; Hamzeh et al. 2009; Seppännen et al. 2010). Other examples relate to the avoidance of rework (Kalsaas 2010; Liu and Ballard 2008) and implementation of continuous flow (Chin 2010; Liu and Ballard 2009; Bulhões and Picchi 2006).

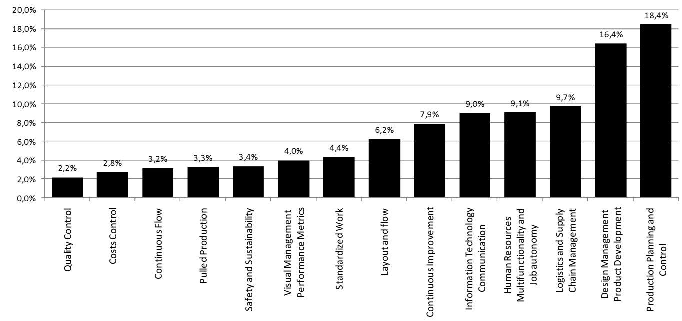

Figure 1: Distribution of keywords in categories of LC practices in percentage terms

The category of practice referred to as design management and product development (16,4% of the keywords) has also been the subject of a number of studies. In particular, how to draw up a good design has been debated over the years, emphasizing topics such as the concurrency of production activities with the design process, the reduction of the design lead-time, and the means for clash detection (Tzortzoupoulus et al. 2001; Tuholski and Tommelein 2008; Jara et al. 2009, Liu and Wang 2009). Other studies had the objective of discussing how to set a target cost and make designs compatible with those costs (Ballard 2006; Robert and Granja 2006; Pennanen et al. 2010). Some studies focused on making designs suitable for the use of prefabricated and modular systems (Pasquire and Connolly 2003; Höök and Stehn 2005; Simonsson and Emborg 2007).

This category of practice has contributed to emphasizing two important concepts into the evolution of LC theory: the client requirements and client value. Many papers have proposed methods for capturing and meeting clients requirements and incorporating them into design (Miron and Formoso 2003; Lima et al. 2008). Reports of capturing and transforming client requirements into a design that satisfy them have been presented (Parrish et al. 2008; Kim and Lee 2010). Such requirements have been sometimes identified based on post-occupancy evaluations (Bordass and Leaman 2007; Way and Bordass 2007). Computational tools (e.g., CAD, BIM and 3D) have been gradually incorporated in the product development process (Tuholski and Tommelein 2008; Pennanen et al. 2010).

The category of practices related to logistics and supply chain management (9,7%) is essential to reduce waste (Vrijhoef and Koskela 1999). Some examples of studies on this subject are: logistic systems design, internal and external logistics to the construction sites, kanban applications, logistics centers managed with standard references (Khafan et at. 2008; Elfving 2010; Hamzeh et al. 2007); analysis of the inter-relationship of supply chains and possible improvements in its management (Sterki et al. 2007; Isatto and Formoso 2006); thorough studies of the supply chain of construction materials, such as those related to wooden frames, metal pipes, steel frame, pipe supports (Melo and Alves 2010; Alves and Tommelein 2006; Huang et al. 2004; Arbulu and Tommelein 2002.)

The category of practice referred to as human resources, multi-functionality and job autonomy was associated with 9.1% of the keywords. Examples studies in this category focused on which skills a manager implementing LC needs to develop (Pavez and Alarcón 2006; Pavez and Alarcón 2007; Pavez and Alarcón 2008), while others emphasized motivation policies and incentives to foster commitment to the production goals (Garcia et al. 2006, Miranda et al. 2007). Yet others investigated the development of skills to deal with uncertainty (Abdelhamid et al. 2009, Christensen and Christensen 2010).

Information technology and communication is a category of practice associated with 9.0% of the keywords. Atkin (1998) developed computer models to control supply chain flows and design management. Rischmoller and Alarcón (2005) analyzed computer visualization tools based on lean principles to improve communication. Much of this technology has been developed to better managing the product development process (Kagiouglou et al. 2003) and the construction processes (Izaguirre and Alarcón 2006).

In the range of 4.0% to 8.0% of keywords are the categories of practices referred to as visual management and performance indicators (4.0%), standardized work (4.4%), layout and flow (6.2%) and continuous improvement (7.9%). Below 4.0% are five categories of practices: safety and sustainability pull production, continuous flow, cost control, and quality control.

DISCUSSION AND CONCLUSIONS

On the one hand, the analysis of the distribution of the keywords in the LC categories of practices points out an emphasis on production planning and control, and design management and product development. In fact, for those two categories there seems to be effective adaptations of practices adopted in the manufacturing industry to the construction environment. In the case of Last Planner®, the abstraction from manufacturing reached a high level, as a specific set of planning mechanisms (e.g., first-run studies) and vocabulary (e.g., work packages) was devised (Ballard and Howell, 1998a, 1998b; Ballard 2000).

On the other hand, categories of practices fairly well disseminated in manufacturing, such as pull production and standardization, have not yet been extensively discussed in the LC community. Concerning pull production, its implementation requires reliability and stability of suppliers. If these requirements are not in place, the upstream processes are not able to supply the downstream processes at the right time and at the right quantity. In fact, since complying with these requirements may be easier in the more controlled environment of a production system external to the site, pull production has been often investigated in the prefabrication industry (Gallardo et al. 2006). Nevertheless, pull production often happens in a construction site due to the very nature of its processes and technologies. For example, mortar and concrete have to be produced just-in-time to supply other processes, otherwise the materials would deteriorate. However, there seems to be room for extending pull production to the relationships between the construction site and its external suppliers of materials consumed in high-volumes and in high-frequency (e.g., bricks during the masonry construction phase). In this case, as it happens in manufacturing, visual controls could be used for triggering replenishment of materials, reducing reliance on bureaucratic centralized controls (Smalley 2004).

Concerning standardized work, the high amount of rework and quality problems in construction sites indicate the necessity for this category of practice. An underlying cause for the few studies on standardized work in construction can lie on the very nature of the LP prescriptions on how to design standard work. Indeed, the practical guidance offered by LP on work standardization is focused on repetitive tasks, subjected to little variation and with short cycle times (e.g., Rother and Harris 2001). Of course, a number of tasks in a construction site have precisely the opposite characteristics, so the adaptation to construction is not straightforward. As a possible alternative, LC researchers and practitioners should pay more attention on the prescriptions for designing procedures in complex socio-technical systems (e.g., Dekker 2003). While in manufacturing it is possible to standardize one product, in construction, it is necessary to develop standard procedures. For example, procedures could be less prescriptive on how to do a task, placing more emphasis on the goals to be achieved and in the provision of the resources to carry out a task (Blakstad et al. 2010; Ballard and Howell 1999).

Is also worth noting that very little emphasis have been placed by LC literature on the training of construction workers. Although the category of practice human resources, multi-functionality and job autonomy was the fourth most often associated with the keywords, the studies are mostly focused on developing the skills of higher hierarchical ranks, rather than front-line workers. This is a major drawback, as it is well-known that a major requirement for a truly lean company is the development of a highly capable workforce (Liker 2004). On the one hand, researchers and practitioners may be resigned with the systemic drawbacks of construction industry, such as the high turnover and low educational levels of most front-line workers. On the other hand, this may reflect deeper assumptions on the nature of construction. Indeed, the proliferation of formal planning and control practices, of which Last Planner® is exemplary, takes for granted that front-line workers know how to do the tasks on a micro level. While this is true, does not mean that tasks in the front-line do not include waste due to a more qualified workforce. From a broader perspective, it seems that LC practices have consistently provided more of the same, in the sense that formal planning and control methods (e.g., Last Planner® and BIM), while providing gains not yet fully exploited by industry, have neglected the design of means to take advantage of front-line workers skills (training was a keyword that represented 0,8% the total). This is in contrast with research conducted in other domains (e.g., medicine and aviation) which are far more advanced than construction in terms of training practices for complexities deals (Patterson and Miller 2010).

Also, two categories of practices that have been fully neglected in the LC literature are certainly applicable to construction sites: total productive maintenance (TPM) and quick setups. TPM could support waste control in construction sites, which can have a number of major (e.g., cranes) and small equipment (e.g., saws) subjected to maintenance routines. Of course, maintenance of such equipment already takes place in construction sites without TPM programs, but this is often due to the requirements of regulations. However, an explicit use of TPM could be insightful, since, for example, greater emphasis could be placed on issues such as autonomous maintenance (i.e., basic routine maintenance carried out by the operators of the equipment), visual warnings on the maintenance status of equipment, as well as a holistic view of their production, safety and environmental impact. Likewise, the core idea of quick setups, which is the externalization of tasks that hinder flow, could be more systematically adopted in construction sites. Indeed, as it happens with pull production, these ideas have been adopted implicitly. For example, gangs set up and sort out the areas in which concreting will occur, before the arrival of the concrete mixer trucks that bring manufactured concrete. In this case, the concreting is likely not be delayed and interrupted due to tasks that could have been anticipated. An explicit use of the principles of quick setups could lead to the application of the same ideas elsewhere in the construction sites, as well as providing additional gains in the tasks it has been already implicitly adopted.

The drawbacks of the LC literature discussed in this item may be drawn, in part, to the hypothesis raised by Pasquire and Connor (2011) that LC relies too much on internal developed material. While those authors found ambiguous evidence for supporting that hypothesis, the lack of a mature set of LC practices can reflect the need for drawing attention to a broader literature. Two examples discussed in this section concern the literature on the management of procedures in complex systems and the literature on workforce training. Concerning opportunities for future studies, resulting from this article, it is possible to stress: (a) the development of new practices to implement LC principles, based on LP practices that have successfully adopted in manufacturing; (b) the development of a protocol on evaluating LC practices, which can help practitioners and researchers to monitor the extent to which a construction company is really lean; and (c) the development of a thorough literature review on the state-of-the-art of LC, which could shed light on the main theoretical gaps and the extent to which theory has been applied in practice. In this respect, an analysis could be specifically made on the IGLC papers written by authors from industry.

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