A PROTOCOL FOR ASSESSING THE USE OF LEAN CONSTRUCTION PRACTICES

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ABSTRACT

The use of Lean Construction (LC) practices has gradually spread in the construction industry. Accordingly, mechanisms are necessary to evaluate their use so as to facilitate identifying strengths and weaknesses in the LC implementation process. This paper presents a protocol for assessing the use of LC practices, which has distinctive characteristics, such as: (a) assigning weighting factors to each practice, according to their degree of importance as attributed by the perceptions of seven experts; (b) establishing explicit conceptual links between each practice and lean principles, (c) selecting practices to be included in the protocol based on a systematic review of the LC literature; and (d) the use of multiple sources of evidence to carry out the assessment, which increases the credibility of the results. The protocol comprises 103 LC practices, distributed over 15 categories. This paper reports the application of the protocol in a residential building project, which allowed identifying its strengths and weaknesses.

KEYWORDS:

lean construction; lean production; audit; protocol

INTRODUÇTION

The gradual spread of LC practices in industry creates the need to develop tools for evaluating their use, with a view to identifying opportunities for improvement and best practices. In this paper, LC practices are defined as management routines based on LC principles, which have been implemented with some degree of standardization and success on construction sites. The practices must be observable and measurable in terms of their efficiency and effectiveness. Categories of LC practices are labels allocated to a set of practices that share similar goals.

Some studies have already been conducted so as to evaluate the use of LC principles and practices (Carvalho, 2008; Hofacker et al., 2008; Salem et al., 2006; Valente et al. 2012). Carvalho (2008) proposed a questionnaire that makes it possible to evaluate the eleven LC principles set out by Koskela (1992), based on the perceptions of representatives from top management, engineering, front-line workers, suppliers, designers and clients. However, the links between the questions that comprise the questionnaire and Koskela's principles are not explicit.

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The study by Hofacker et al. (2008) was developed in partnership between research centers in Germany and Brazil, and it was based on the principles of Womack and Jones (1996) and Koskela (1992) which were divided into 6 categories, namely: focus on the client; awareness of waste; quality; materials flow; organization, planning, information flow; and continuous improvement. Similarly to the study by Carvalho (2008), the conceptual links between assessment requirements and lean principles are not explicit. Salem et al. (2006) reviewed LP and LC principles, and drew up an evaluation protocol of six LC practices: Last Planner; fail safe for quality; 5S; visual management; huddle meetings; and first-run studies. The protocol enabled a company that had been implementing LC to make significant improvements in its performance, after applying the protocol over three rounds.

Valente et al. (2012) set out a protocol for assessing LC practices which was drawn up in accordance with the specific needs of a company. Thus, there was an emphasis on some practices to the detriment of others, which, in this case, were not used or were not relevant. Moreover, the selection criteria of the practices were not clearly presented in their study. Also, both the studies by Salem et al. (2006) and Valente et al. (2012) did not involve a pilot application. It is worth noting that one aspect common to all four studies cited (Carvalho, 2008; Hofacker et al., 2008; Salem et al., 2006; Valente et al., 2012) is the lack of evaluating the importance of the LC practices from the perspective of LC theory. The assumption of those studies is that all practices have the same importance. Moreover, there are also studies, the purposes of which were to develop methods for auditing specific LC practices. For example, Reck (2010) proposed a protocol for evaluating best practices in production planning and control.

Thus, the main objective of this paper is to set out a protocol for auditing LC practices, which can be distinguished from previous studies in the following matters: (a) assigning weights to each practice, based on experts opinions; (b) establishing conceptual links between each practice and lean principles; (c) selecting the practices included in the protocol based on a systematic review of the literature on LC; and (d) the use of multiple sources of evidence to carry out the assessment, which increases the credibility of the results. In practical terms, the protocol aims to contribute to identifying both the maturity of LC practices and opportunities for improvement in the project.

RESEARCH METHOD

OVERVIEW OF OF THE RESEARCH METHOD

This study was conducted in two main steps: (a) drafting the assessment protocol of LC practices, based on a literature review; and (b) applying it in a construction company. The development of the protocol was divided into three sub-steps: (a) defining the practices to be assessed (Step 1A); (b) defining the sources of evidence that would enable the practices to be evaluated (Step 2A); and (c) defining a scoring system, based on experts´ opinion, for evaluating the relative importance of the practices (Step 3A).

The application of the protocol was also divided into three sub-steps: (a) a pilot application on a project with a view to identifying needs for improvements in the protocol (Step 1B); (b) applying the refined version of the protocol on the same construction project (Step 2B); and (c) a meeting where the results were presented to a manager of the company where the study was carried out (Step 3B). This meeting was also an opportunity to obtain feedback from the manager about the strengths and weaknesses of the protocol.

DESIGNING THE PROTOCOL

Step 1A – Defining practices

The categories of practices to be assessed were defined based on the results of the study by Etges et al. (2012) who, having analyzed the key words of articles published between 1993 and 2010 in IGLC Conferences, grouped them into 15 categories. The categories are: Human Resources (HR), Continuous Improvement (CI), Work Standardization (WS), Work Safety (JS), Layout (LA), Quality Control (QC), Logistics and Supply Chain Management (LSC), Information Technology and Communication (ITC), Pull Production (PP), Visual Management (VM), Production Planning and Control (PPC), Sustainability (SUS), Design Management and Product Development (DMPD), Costs Control (CC) and Continuous Flow (CF).

The practices that comprise each category were identified from: a re-analysis of the papers reviewed by Etges et al. (2012); and the existence of conceptual links between the practices cited in the papers and the five LP principles defined by Womack and Jones (1996). The use of the principles put forward by Womack and Jones (1996) arises from their capturing essential features of lean philosophy succinctly in five principles. According to Koskela (2000), Womack and Jones (1996) discuss the concept of transformation superficially, but even so they synthesized fundamental LP characteristics in their principles.

Step 2A – Defining the sources of evidence

Three main types of sources of evidence were used: (a) observing the practices; (b) analyzing the documentation of the practices; (c) interviewing those in charge of carrying the practices out. Some of the sources of evidence were accessed on the building site and some from the company's office. The use of multiple sources of evidence is a well-known good practice of auditing, as recommended by Chiesa et al. (1996) and the standard ISO 19011.

Step 3A – Defining the scoring system

The assessment of each practice can be expressed quantitatively, in three levels: a score of zero for not being applied; a score of 0.5 for being partially applied and a score of 1.0 for being fully applied. It is also possible to attribute non-applicability to the practice when the characteristics of the contruction project do not require or do not make it possible to use it. After the pilot application (Step 1B), shortcomings of the scoring system adopted were noticed. Initially, it used equal weights for all practices. As a result, there were practices of great importance to the principles of LC with the same impact on the final score as that of practices of less importance. To improve the scoring system, the protocol was submitted to a panel of LC experts in order that they could assign a weighting factor (WF) to each practice as per the importance of the practice evaluated in relation to LC theory. All of them hold a Master’s degree or a Doctorate in areas correlated to LC or some of its principles. All have an academic connection with some national or international educational institution, as doctorate students or as teachers.

The protocol was sent to a group of 18 experts to assign a value from zero to four to each practice as per its importance to LC principles, as follows: 0 for practice without regard to LC principles (this practice could be eliminated from the protocol); 1 for practice with little relation with LC principles; 2 for practice with an average relation with LC principles; 3 to a practice having a major relation with LC principles; and 4 to a practice that strongly demands LC principles. The weighting factor resulted from the average of the results obtained from the return of seven experts. The calculation formula for assigning a performance score to each practice, category of practice or the whole construction project was set, as per Equation 1.

$$Performance\ score = \frac{\sum PO_i \times WF_i}{\sum PO_i \times WF_i - \sum practices\ NA_i \times WF_i}$$

$Where$:
$PO_i = Performance\ obtained\ (0; 0{,}5\ or\ 1)$;
$WF_i = Weighting\ factor$;
$NA_{i\ practices} = non\ applicable\ practices.$

Equation 1

The score of each category of practice or of the project as a whole can be expressed in percentages, and take into account the ratio between the points obtained in the evaluation and the maximum points possible for that category of practice or project. The maximum points possible result from summing the WFs of the practices applicable in the categories of practices or in the project. The WFs were also used in analyzing the compliance of the project with the five LP principles proposed by Womack and Jones (1996). Thus, another result made feasible by the protocol is checking the compliance of the project and the company to these principles.

CASE STUDY

After the theoretical development of the protocol had been completed, it consisted of 15 categories of practices and 105 practices. Then, contact was made with a large construction company based in Porto Alegre, southern Brazil. The company is well-known for using advanced management practices and it was available and interested in the subject of this study.

Step 1B – Pilot application of the Protocol

The aim of the pilot application was to evaluate the protocol as to: the availability of the sources of evidence requested; the clarity of the textual formulation of the practices; and the time consumed to apply the protocol. The pilot application, taking the collection of all necessary data into account, consumed about 2.5 h. Interviews were carried out with: an engineer, three bricklayers and two plasterers, the storekeeper, the hoist operator and the administrative assistant. As results from the pilot application, fifteen practices had their descriptions or sources of evidence reformulated. Questions about the company (e.g., past experiences with LC, level of standardization of production management practices across projects, etc.) and about the project analyzed (e.g., number of workers, use of subcontracted wokers, etc.) were also incorporated into the protocol, since this helped to characterize the broader context in which LC was used. Moreover, as already mentioned, the pilot application enabled deficiencies in the scoring system to be identified.

Step 2B – Application of the refined version of the protocol

After refining the protocol, a new application was carried out in the same company and building site. The final version of the protocol has 15 categories of practice with 103 practices linked to references in the literature and to the five principles of Womack and Jones (1996) and with their respective WFs defined. Part of the protocol regarding the category of Pull Production practices can be seen in Appendix A.

The practices were evaluated in the same sequence in which they are presented in the protocol. A visit was made to the building site to evaluate practices such as visual management and continuous flow, Interviews were carried out with: the engineer, front line workers, the storekeeper, the hoist operator and the administrative assistant, and the work safety assistant. In the company's headquarters, a meeting was requested with representatives of the product development department and of the project management of the site visited, as well as with a representative of the costs department. Applying the whole version of the protocol in the building site and in the company´s headquarters lasted about 4.0 hours.

Step 3B – Meeting to present the results and to verify the usefulness of the protocol

The meeting at which the results were presented and the usefulness of the protocol was verified took place with the company´s manager who led the implementation of LC practices in all projects of the company. In fact, that manager provided support to the researcher over stages of the study, facilitating access to interviewees and documents requested by the protocol.

RESULTS

WEIGHTING OF THE PRACTICES BY THE GROUP OF SPECIALISTS

The experts' assessment reflects the importance of each practice as to LC principles. Figure 1 shows the mean scores obtained for each category of practice. Figure 1 indicates that the categories of practices of LA (Layout), PP (Pull Production), VM (Visual Management) and QC (Quality Control) are identified as being of greatest importance. On the other hand, the practices that comprise the categories of ITC (Information Technology and Communication), CC (Cost Control) and SUS (Sustainability) are those which, according to the experts, have lesser importance with regard to LC principles.

In the study of Etges et al. (2012), the categories of practices with the largest number of keywords related to them were PPC (Production Planning and Control), DMPD (Design Management and Product Development), LSC (Logistics and Supply Chain Management) and HR (Human resources), with 18.4%, 16.4%, 9.7% and 9.1% respectively (right axis of Figure 1 right). According to Etges et al. (2012), these are the categories of practices most studied in IGLC. However, PPC, DMPD, LSC and HR, correspond to the sixth, eighth, twelfth and eleventh most important practices, respectively according with the expert's evaluation. Regardless of the small number of expert's questioned, Figure 1 points to a disagreement over what is most researched and what was considered most important. Thus, a question can be raised: does what has been most studied by the IGLC community represent what, in fact, is most important for LC principles? Of course, it is possible that some practices may not have been widely studied in IGLC, although they are important, because researchers consider that enough knowledge about them had already accumulated, such as the layout of the construction site.

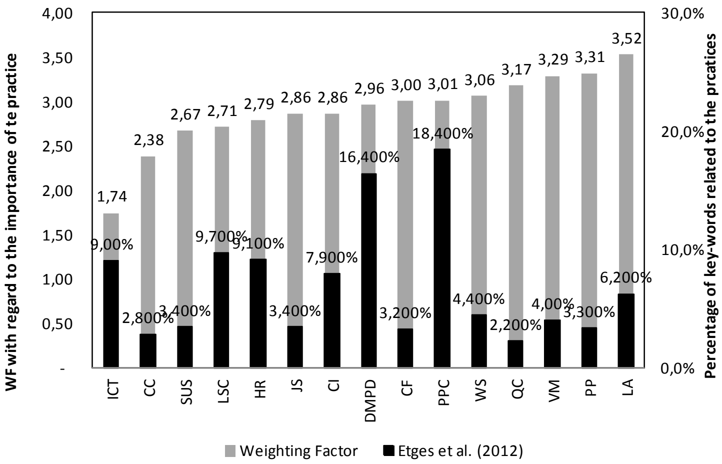

Figure 1: WFs obtained by practice category compared with the percentage of key-words identified in each practice category in Etges et al. (2012)

RESULTS FROM THE CASE STUDY

The application of the protocol allowed the identification of a number of opportunities for improvement and the use of best practices in the investigated construction project (Table 1).

Evaluation as to the usefulness and ease of applying the protocol

The manager interviewed in the meeting in which the results were presented pointed out the benefits of using the protocol in the company, as it enabled opportunities to improve and enhance internal management processes to be identified. The manager reported the company's interest in extending the application of the protocol to its other sites with the aim of obtaining an overall view of the projects and of the company´s departments that interact directly with the building sites. Furthermore, the interviewee considers that applying the protocol can be a tool for training engineers in LC principles and practices. This would be particularly important since the manager recognized that most of the company´s staff lacked knowledge of LC theory.

The broad scope of the protocol was also stressed positively by the interviewed manager. In fact, the results can be analyzed separately for a set of practices or categories of practices. Also, it is possible to calculate an overall score for each project. Due to this broad scope, the protocol is not so quick to apply like that of Hofacker et al. (2008), who reported an application time of about 1.5 hour. In this case study, collecting data took up about 4 hours. In addition, there was a period needed to present and discuss the results with a company´s representative, which took 2 hours.

Table 1: Best practices and opportunities for improvement identified

Category of practice	Practices that stand out	Opportunities for improvement
Quality Control	(a)Existence and application of work standards cards involving quality criteria of the product delivered; (b) Training staff as to the quality criteria required; (c) Verification of customer satisfaction and the quality of the product delivered.	(a) Develop an action plan on nonconformities of quality perceived in the control of the activities carried out; (b) Only consider the activities 100% completed in the physical and financial plan after all outstanding quality matters have been settled.
Pulled Production	(a) FIFO system for inventory control and visual identification of inventory; (b) Brick-laying kanban well developed on the site. Team applies and knows the reason for applying the procedures.	(a) Develop a list of substitute tasks that could be put into production in the short term; (b) Improve the system of delivering materials with external suppliers who can work in JIT with the site works.
Work Safety	(a) Application of PPS to plan safety items required to develop activities; (b) Involvement and commitment of the site management in the PPS.	(a) Resume work on the management of near misses that has already been used in the company.
Contínuous Flow	(a) Practice of control and defining a takt time for macro activities.	(a) Introduce practice of the value stream mapping for the main activities; (b) *Takt* time for the activities at the operational level.
Visual Management	(a) There is visual indication with production information (kanban, traces of mortar); (b)People and equipments movement areas are well identified; (c) Subcontractors performance information, performance index posted in an evaluation table.	(a) Implement the work on the practice of 5S.
Work Standardization	(a) Development of a prototype apartament to apply all the services for the first time and check for possible incompatibilities; (b) Defining the standardized flow of activities for structure and brick-laying; (c) Training staff within the standards.	(a) Develop routine, with frequency laid down, for reviewing the standard procedures.
Layout	(a) Lookahead plan for supplies that defines the lead time for delivery of materials needed for planning on the construction site.	(a) Site Layout review as the works progress. Study of layout of the site did not represent the situation at the time of data collection.
Continuous Improvement	(a) There is a search for incorporating technological innovations on the construction site, whether as construction solutions or tools to improve the management performance of the works.	(a) Develop problem-solving group to work on non-conformities found in the work; (b) Formalize the development of best practices.
Human Resources	(a) There are policies to motivate staff who exceed the salary incentives.	(a) Develop system for evaluating employees (foremen, trainees, administrators); (b) Give feedback from the evaluation to these employees; (c) Establish performance goals for these employees; (d) Train employees to develop autonomy in identifying and correcting faults in the production process.
Logistics and Supply Chain Management	(a) There is a procedure for receiving, handling and stocking materials; (b) There is long-lasting relationship with suppliers; (c) The company has developed many of the companies providing services such that there is a commitment to quality requirements in their procedures; (d) Development of a medium-term plan for hiring - Lookahead supplies - linked to executive planning of the works.	(a) Develop evaluation system for supplies by the works as to: (i) quality of product/service contracted, (ii) service at forecast cost, (iii) service on time, (iv) conditions of delivery and unloading of material.
Design Management and Product Development	(a) There are quality and compatibility procedures that are applied prior to finalizing and delivering projects; (b) Wanted alternatives modularized or pre-assembled alternatives are sought for some items; (c) There is a customer satisfaction survey as the characteristics of the product delivered.	(a)Develop the Last Planner from the short-term view by assigning responsibility to the project engineers and design teams; (b) Develop feedback procedure on the works in relation to the project and use this information to develop new projects: (i) number of problems of project incompatibilities; (ii) number of requests for project alterations.
Production Planning and Control	(a) There is macro planning, updated weekly; (b) There is medium-term planning; (c) Short-term planning determines the activity, location of the activity, the team responsible and deadline for carrying it out; (d) There is a periodic report on the works that presents physical progress indicators and the productivity of the works. This report is submitted monthly to the company's board.	(a) Apply short-term planning meetings weekly involving those in charge of work and subcontracted teams at a fixed time and place; (b) Discuss in the short-term meetings the cause of non-fulfilment of scheduled activities; (c) Formalize the PCP process - short and medium term developed with the works teams; (d) Use the medium-term schedule so as to generate a list of substitute activities without restrictions that may be put into production in the short term; (e) Apply the process of removing restrictions from activities at the medium term level so as to put them as short-term alternatives.

CONCLUSIONS

This study introduced a protocol for assessing the use of LC practices. The protocol is a comprehensive audit document, which encompasses LC practices linked with lean principles, weigthning factors, and sources of evidence. These features differentiate this study from other assessment protocols already developed to evaluate LC practices and principles. In order to apply the protocol, it is essential that the evaluator is thoroughly familiar with LC. Moreover, the application of the protocol makes more sense in companies that are formally committed with the use of LC. This may be a drawback, as there are few construction companies that adopt the use of LC as a corporate policy. Another important result of this study is the identification of divergences between the percentage distributions of keywords identified by Etges et al. (2012) and by the experts´ evaluation of their importance. Of course, in order to give more consistency to this result, it is suggested the number of experts consulted to assess the practices of this protocol be increased.

An important limitation of the protocol is concerned with the fact that no evaluation is made of the interactions among LC practices. In fact, LC is known to be a complex system of several interacting elements, such as management practices, people, technologies and the external environment. However, no model of the systemic nature of LC has been proposed so far, which hinders the incorporation of this topic into the protocol. Also, the protocol lacks external validity, as it was applied in a single project. Additional applications, in different contexts, are expected to result in improvements in the protocol and greater generalizability. Nevertheless, the protocol has good internal validity, as the procedures adopted for its design are explicit and replicable. Some pieces of evidence of internal validity can be stressed, such as: the practices were selected based on a systematic literature review, rather than on random choice of the researchers; it proposes the use of multiple sources of evidence, thus allowing for triangulation of sources of data; and the weighting factors were assigned by other academics, rather than the designers of the protocol.

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Appendix A: Example of the Protocol for the Production Practice of Pull Production

	Practice	Sources of evidence	References	Principle of Womack & Jones (1996) attributed	Conceptual link between LP practice and principles defined by Womack & Jones (1996)	WF
PULLED PRODUCTION						
1	There is visual identification of the points of replacing stocks.	* Check to see if there is a way to mark the minimum limit of stocks that signals the point of replacement where	Arbulu et al. (2003), Sterki et	Pull	Identifying limits of replacing stock which "pull" its supply.	3,29
2	Visual communications are used to control production and tranport (kanban).	*Interview the engineer on the use of kanbans on the building site; *Check to see if there are cards which establish the start of transport activities and production activities; * Check to see if the activity only begins after the receipt of the card which determines when it begins; * Check to see if the displacement of materials is coordinated by exchange of cards between the client teams and places in which materials are stored;	Arbulu et al. (2003), Khalfan et al. (2008), Jang e Kim (2007), Tezel et al. (2010), Brodetskaia et al. (2010), Nagakawa (2005).	Pull	Using visual devices which communicate when the internal client requests the product and this movement kick starts production.	3,57
3	Internal distribution of the materials on the building site is carried out in accordance with the demand from internal clients.	* Check to see if there is a board or document with the schedule for delivering materials internally to the site; * Check to see if there are kanban cards which signal the need for materials by internal clients.	Ballard (1997), Ballard (2000).	Pull	Determining deliveries of consumables as per the demand from internal clients.	3,71
4	There is a list of substitute tasks withour restrictions in the medium term which are posted and	*Verifiy documento witha list of activities without restrictions, a result of look-ahead.	Ballard (1997), Ballard (2000).	Pull	Planning the sequencing of the activities. The conclusion of one activity "pulls" the start of the	2,43
5	There is development of a network of suppliers, for soem items of production, which activate JIT by using kanban for delivery of	* Interview engineer on JIT with external suppliers; * Verifiy document which controls orders and delivery of materials by external suppliers.	Khalfan et al. (2008), Hamzeh et al. (2007).	Pull	Determining deliveries of consumables to a JIT system which starts outside the building site.	3,57