IMPLEMENTING A PERFORMANCE IMPROVEMENT STRATEGY FOR REINFORCED MASONRY BUILDING CONSTRUCTION

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ABSTRACT

Twenty years after the first annual conference of the International Group for Lean Construction, it is evident that Lean Construction (LC) concepts have been implemented in many projects at both operational and organisational levels. Several papers have analysed how to improve traditional management techniques through reducing wasteful practices and increasing collaboration among participants. However, there are still firms in which LC ideas have not been implemented. This paper presents the results of a study focused on formulating a proposal for a construction company in order to improve the performance of on-site activities in social housing projects. The aim is to develop a performance improvement strategy so that variability can be reduced in reinforced masonry tasks.

The research involves processes related with masonry walls and concrete slabs construction. The project under analysis consists of 23 six-story buildings with 552 apartments in total. Data collection methods include survey-questionnaires, face-to-face interviews, direct observations, and time-lapse recordings. The paper is divided in three parts. First, the procedures are characterised in terms of the Transformation Flow Value (TFV) theory. Subsequently, on-site operational improvements are suggested. These are directed towards increasing compliance with seismic, quality, and health-and-safety regulations. Thirdly, a discrete-event simulation model is designed in order to show the benefits of reducing variability within building processes. Conclusions offer guidelines to implement basic LC concepts and recommendations for applying LC tools.

KEYWORDS

Productivity improvement, reinforced masonry, discrete-event simulation

INTRODUCTION

Over the last years, there have been several papers about how to apply LC in different projects and construction industries worldwide. Some of those investigations have examined how the new production paradigm can be implemented at both strategic and operational levels. Barros and Alves (2007) present, for example, a study focused on discussing some factors for successfully linking lean ideas with corporate business

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strategies. Moreover, Mitropoulos and Howell (2001) give some general guidelines about the necessary conditions for applying LC ideas for on-site activities. Although the investigations have been carried out in different countries, all of them highlight the importance of starting to apply LC tools at the site level.

Despite these efforts, there are still many companies and construction projects in which LC ideas have not been applied due to lack of interest or knowledge. Reinforced masonry building construction in Colombia is one of those sectors that have not widely experimented with the application of Lean. Although Guevara et al. (2011) show a successful implementation case, LC concepts are not consciously implemented in the majority of masonry-related Colombia construction projects.

This paper aims to offer some basic guidelines regarding how to start applying LC ideas for low-income housing projects. In order to do that, a brief discussion focused on lean implementation is presented. Subsequently, the investigation is divided in three parts. Firstly, waste is characterised for activities, such as, wall erection, grout filling, and slab construction. Secondly, some of the current quality and safety practices are analysed. Thirdly, a discrete-event simulation model is designed in order to show the benefits of reducing variability within building processes. Finally, an implementation strategy is proposed.

IMPLEMENTING A PERFORMANCE IMPROVEMENT STRATEGY

Achieving change in the construction industry is a real challenge. Koskela et al. (2003) describe how many different countries have tried to implement national renewable construction initiatives. Although programs, such as, FIATECH (U.S.A) and Rethinking Construction (U.K) have definitely helped to enhance performance indicators, there is still a need for a more systemic change. According to the mentioned authors, a more holistic conversion has to be based on a new production philosophy focused not only on the transformation view, but also, on the flow and value perspectives. Since such dramatic alteration cannot be easily accomplished, Koskela et al. (2003) suggest to start by examining operational processes.

Although it is clear that transforming an entire industry (e.g., the residential construction industry) may take several years, there are some specific examples showing that achieving a systemic change is possible. Barros and Alves (2007) examine three different Brazilian building companies in which some LC ideas have been successfully implemented. Their study concludes that there is a series of factors that influence a correct LC improvement strategy. Among such factors, it is important to highlight that in the three cases under analysis, change started to be implemented through a bottom-up approach and was supported by a continuous learning process. Azevedo et al. (2010) confirm these results and emphasise the fact that an improvement strategy can also be triggered by industry-related events or specialised consultants focused on encouraging LC ideas.

In Colombia, there have been some residential construction firms that have started to implement LC ideas. Guevara et al. (2011) analyse a case study in which concepts related with the Last Planer System (e.g., short-term meetings, lookahead planning committees, etc.) were applied for developing a low-income housing project. The authors argue that a new model of production could be implemented in such case because of three main issues (as suggested by Mitropoulos and Howell, 2001): both management personnel and workers spent sufficient time on enhancing operational processes; new skills and mechanisms were developed in order to achieve and sustain a better on-site performance; and corporate directors were interested in implementing a process-focused improvement strategy.

Applying the guidelines given by authors, such as, Koskela, Mitropoulos, Howell, and Barros is not an easy task. The residential project analysed in this paper is a clear example of that. Although the company in charge of the project is a very organised firm, it has not perceived the need for enhancing its operational performance. For such reason, this research is focused on highlighting potential operational improvements in areas related with quality control, health and safety, and production processes. Based on those prospective operational enhancements, a productivity improvement strategy is proposed through following the methodology described in the following section.

RESEARCH METHOD

The research strategy selected for this investigation was the exploratory single-case study approach. The methodology was considered exploratory due to the lack of previous researches focused on implementing LC ideas in reinforced masonry construction processes for labour-intensive and low-income housing projects. The case study approach was chosen because of three main reasons: (i) it was necessary to explore a phenomenon within its real context; (ii) this type of academic inquiry allowed to rely on many sources of evidence and multiple data collection methods (Yin, 1994); (iii) the reinforced masonry system is one of the most widely used structural techniques for developing Colombian low-income housing projects.

The research approach sough to answer the following question: how can a Colombian construction company start applying some LC ideas for improving operational tasks in low-income housing projects? Since the research was based on a single project, three units of analysis were defined. All of them were based on the same work-face activities (i.e.: reinforced-masonry wall erection and reinforced concrete slab casting). The first unit was focused on characterising the production process and identifying wasteful practices. The second one analysed the on-site procedures from a quality-and-safety perspective. The third analytical component examined variability within the processes through a simulation exercise.

The study employed multiple data collection methods, such as, a literature review, questionnaires, productivity ratings, and observation exercises (i.e.: site visits and time-lapse recordings). The review included investigations focused on implementing productivity improvement strategies and topics concerned with with the three units of analysis. Interviews and questionnaires were conducted on both management personnel and workers. Additionally, for productivity-rating purposes, activities were classified in value added, contributory, and non-value added task. Finally, site visits and recordings were performed according to Oglesby et al. (1989).

CASE STUDY DESCRIPTION

The research took place in a medium sized social housing construction company. This firm was chosen because it is nationally recognised as an organisation that delivers good quality and well-designed products. Moreover, its corporate directors had previously shown some interest in promoting innovation within their projects.

Such interest, in conjunction with their lack of concern about implementing LC ideas, contributed towards analysing the selected project.

The study is based on a residential project that comprises the construction of 23 six-story buildings with 552 apartments in total (i.e.: four apartments of $45m^2$ per floor). The dwellings are reinforced masonry buildings that serve as housing solutions for low-income families. The structural system is characterised by employing hollow masonry walls and cast-in-place reinforced slabs. The walls are reinforced with horizontal steel bars (i.e.: placed in mortar joints) and vertical steel rods located in some of the grout-filled core sections of the bricks units. The slabs usually have a thickness of 100 mm (Moroni et al. 2004). These processes are the two most important work-face activities due their labour and equipment consumption rates.

The construction of the structural work (i.e.: walls and slabs) for a typical floor (i.e.: four apartments) may take around seven to eight days. This involves masonry-related tasks, such as, bricklaying, installation of electrical and natural gas conduits, steel placement, and grout filling. It also comprises slab construction procedures, such as, formwork fixing, positioning of the hidro-sanitary and electrical piping system, steel placement, and concrete pouring and hardening. A more detailed description of the construction process is presented in Table 1.

Table 1: Construction Process Description for a Typical Floor

ID	Activities	Sub-Activities	Duration (hours)	Predecessors
A	Masonry Walls "Floor n"	Wall marking, wall elevation; electrical hydraulic and gas pipes	15	Completion of reinforced concrete slab for "Floor n"
B	Mortar hardening	Mortar hardening	5	A
C	Grout filling "Floor n"	Grout filling	10	B
D	Grout hardening	Grout hardening	5	C
E	Concrete Slab "Floor n+1"	Formwork fixing and steel placement; hydro-sanitary and electrical pipes; concrete pouring	15	D
F	Concrete hardening	Concrete hardening	12	E
Total Masonry Area (m2): 285. Total Slab Area (m2): 194				

Generally speaking, Table 1 shows that operational activities include both waiting tasks and conversion processes. The former include procedures B, D, and F. In contrast, tasks A, C, and E are not only the ones with the longest duration, but also, those that utilise most of the available resources. For instance, these three operations share a variety of equipment, such as, a tower crane and a portable mixer. Similarly, they are the most labour-intensive activities with 172 (i.e.: seven craftsmen and three helpers), 50 (i.e.: one mason and four helpers), and 252 labour-hours (i.e.: 13 craftsmen and eight helpers) respectively.

WASTEFUL PRACTICES AND IMPROVEMENT OPPORTUNITIES

Since the beginning of the LC movement, there has been an interest for identifying and correcting waste and its causes. Serpell et al. (1995) argue that work inactivity and ineffective work are the two main categories of waste. Alarcón (1994) agrees with Serpell and provides some tools for detecting waste in construction processes. Among them, it is important to highlight the use of work sampling to identify waste categories. According to Oglesby et al. (1989), it consists in categorising processes as productive, contributory and non-contributory work.

The structural work activities (i.e. tasks A, C, and E from Table 1) were analysed through direct observation, time-lapse recordings, and 5-minute surveys. Although several procedures were examined, only the two most critical are presented here due to space limitations. These are the ones associated with tower crane movements and bricklaying operations. The analysis for both tasks is presented in Table 2.

Table 2: Waste Categories

Operation	Work Category	%	Processes
Tower crane movements	Productive	39	Transport of grout, mortar, bricks, and formwork.
	Contributory	33	Loading and unloading bricks and handling tools from transport cage
	Non-Contributory	28	Waiting time due to lack of space, lack of visibility, congestion, and problems with the hook.
Bricklaying	Productive	63	Laying bricks and mortar
	Contributory	24	Brick transport (less than 10 m), wall plumbing, wall levelling, scaffolding, wall cleaning, and unloading procedures.
	Non-Contributory	13	Brick transport and waiting time (lack of materials).

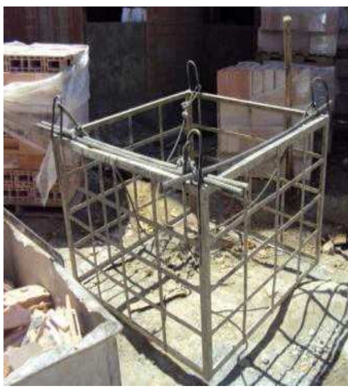
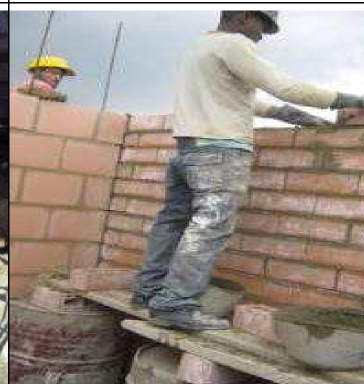
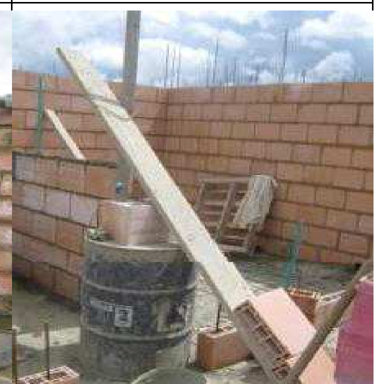
Although waste has been classified in Table 2, such classification does not specify the causes for contributory and non-contributory processes. These can be categorised as both organizational and technological. The former category relies on the fact that there is not a production plan for the activities under analysis. For instance, the tower crane operator and bricklayers do not previously know the quantity of bricks and mortar they have to move and utilise on a daily basis. The latter is about the poor-quality tools that workers employ for performing their tasks (see Table 3).

Evidently, there are many opportunities for enhancing the on-site construction operations. In terms of managerial and organisational issues, it would be good for the company to start using planning techniques such as the line of balance and begin to apply transparency practices as described by Tezel et al. (2010). On the other hand, the firm would take advantage of better transport cages, proper scaffolds and new plumbing elements. These can be either bought in the local market or designed by the company itself; for instance, Guevara et al. (2011) provide an example of a new wall-plumbing device produced by a Colombian construction firm.

TOWARDS BETTER QUALITY AND SAFETY PRACTICES

The concept of quality is essentially related with LC ideas. According to Marosszeky et al. (2002), Koskela argues that systems with quality problems share two main characteristics: poor deviation detection mechanisms and long periods of time between detection and correction. These authors also claim that the majority of quality issues arise as a result of the motivations and attitudes of both management personnel and operatives. They conclude that quality should not only be managed through contractual mechanisms, but also, through exerting a greater emphasis on production planning.

Table 3: Tools employed during masonry processes.

Transport Cage	Scaffolds and handling tools	Wall Plumbing device
		
The cage does not facilitate loading, hoisting, and unloading operations.	The scaffold is not ergonomic, takes time to be built and does not provide a clean and free-movement space.	The device takes time to be built and occupies too much space.

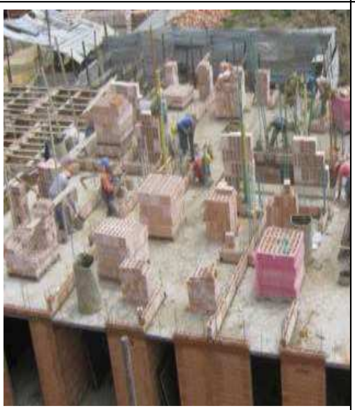
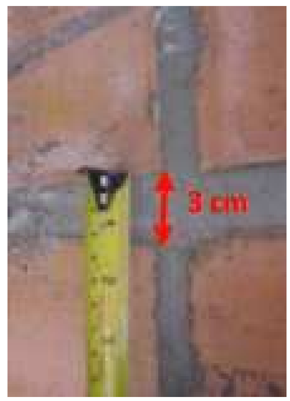
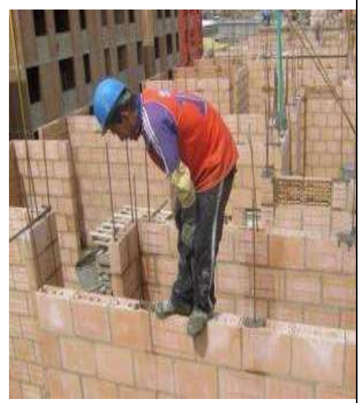
On the other hand, in terms of safety practices, Saurin et al. (2002) contend that it is not enough to comply with mandatory regulations in order to achieve a zero accident target. In order to accomplish such goal, they claim that is necessary to fully link safety with production.

Based on Marosszeky's and Saurin's ideas, a series of quality and safety practices were documented in order to highlight the operations in need for improvement. The main findings are summarised as follows (for figures, see Table 4):

- Disorganised workplace: there is always a lack of space in the floor area because material location and wall construction are not correctly planned.
- Lack of compliance with the Colombian Seismic Code: the mortar joint reinforcement is not correctly placed. The development length of the horizontal steel bars does not comply with the structural design provided.
- Errors in on-site mortar delivery: there are two types of mortar produced on site (i.e.: for the façade walls and for the interior walls). Both have different mix designs.

- Excessive mortar joint thickness: the seismic code specifies a maximum thickness of 13 mm. Some of the observed joints have a thickness between 25 mm and 30 mm.
- Inadequate piping system installation: there are several re-works due to incorrect location of electrical pipes in both the slab and the masonry walls.
- Lack of personal protective equipment (PPE) for working at height: workers do not have the necessary PPE at the moment of pouring grout into the brick cells.

Table 4: Current Quality and Safety practices

Disorganised workplace	**Mortar Joint**	**Work at height**
		

ANALYSIS OF OPERATIONS THROUGH SIMULATION

So far, it is clear that, for the project under consideration, there is a need for improvement in terms of reducing wasteful practices and complying with quality, safety, and seismic-related regulations. Based on that, it was observed that productivity within construction operations could also be enhanced. A discrete-event simulation model was developed in order to analyse the behaviour of the current production system and propose a new operational strategy. This was generated through considering the following activities: general documentation of the construction processes (i.e., direct observation, photography, and video), conceptual modelling, duration and productivity data collection (i.e.: surveys and interviews), coding in ExtendSim Simulation Software, and validation of the model through a comparison with the real processes (Schramm et al. 2008).

The model is based on the operations presented in Table 1. Although such activities represent the construction of the structural work for one floor, the simulation exercise was designed to exemplify the development of five 6-story buildings (i.e.: the structural work for 30 levels). Initially, the current-state (observed event) was simulated and validated. Subsequently, 10 different events were generated in order to evaluate indicators related with duration, cost, and productivity. Unfortunately, these could not be tested in the real process.

The variables under analysis include the following: number of floors ready to install formwork and pour concrete at time equals to 0 (t=0); number of floors ready to start brickwork at t=0; number of floors ready to start grout filling at t=0; number of concrete crews; number of masonry crews; and number of grout-filling crews. Additionally, it was considered that there was only one tower crane, a portable concrete mixer, and a single brick-cutting machine. Table 5 and 6 summarise the previous information (the observed scenario is the event 0).

Table 5: Simulation Scenarios

Variables	**Events**										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Floors ready for concrete pouring t=0.	2	1	2	3	1	2	3	4	4	3	3
Floors ready for brickwork t=0.	2	0	0	0	2	2	2	2	4	3	3
Floors ready for grout-filling t=0.	0	0	0	0	2	2	2	2	2	3	0
Number of Concrete Crews	1	1	1	1	1	2	2	2	2	3	2
Number of Masonry Crews	2	1	1	1	2	2	2	2	2	3	3
Number of Grout-filling Crews	1	1	1	1	2	2	2	2	2	3	2

Table 6: Productivity Indicators for the Construction of 30 Floors

Indicators	**Events**										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Mean Duration (hours)	583	1432	748	585	581	319	317	316	324	239	319
Labour-hours (LH) (Thousands)	47.6	94.1	49.1	38.4	52.4	35.4	36.4	37.4	38.3	37.5	41.8
Productivity (floor/LH) (10E-3)	0.63	0.32	0.61	0.78	0.57	0.85	0.82	0.80	0.78	0.80	0.72
% Utilisation concrete workers	87	35	68	87	87	80	80	80	78	71	80
% Utilisation masonry workers	42	32	61	78	42	77	77	78	81	71	53
% Utilisation grout-filling workers	54	20	39	50	29	52	52	52	54	49	50
% Utilisation tower crane	27	10	20	26	27	49	49	49	50	67	50

Since Event 0 represents the current state, it can be observed that this process starts when there are two groups of 2 floors ready for concrete pouring and brickwork respectively. Such procedure takes around 583 hours and 46.6 thousand labour-hours to be completed with a productivity rate of 0.63x10E-3 units (i.e.: floors) per labour-hour. The results were validated on site and were used to develop the other 10 scenarios. These include an increase in manpower for concrete, masonry, and grout-filling activities. They also take into account a further increment in the ready spaces (i.e.: floors ready for concrete pouring, brickwork, or grout-filling). All the scenarios are shown in Table 5. In such table, it is clear that all the events have a different set of variables. For example, the Event 1 is based on 1 floor ready for concrete pouring, 1 concrete crew, 2 masonry teams, and 1 grout-filling gang.

According to the results shown in Table 6, the Event 5 has the highest productivity rate with one of the lowest durations. It also has one of the top resource utilization ratios. Although this may be interpreted as a desirable future state, it is important to consider that such scenario will not be real unless project complexity can be properly managed (e.g., quality problems need to be corrected and wasteful practices need to be eliminated). This can be achieved through controlling not only resource utilisation rates, but also, workflow variation patterns (Howell et al. 2001).

A PERFORMANCE IMPROVEMENT STRATEGY

The previous sections have examined work-face activities in a low-income housing project through focusing on three units of analysis. Some wasteful practices have been highlighted, problems related with quality and design specifications have been identified, and a discrete-event simulation model was generated in order to show the benefits of a better production strategy. All these three areas have been incorporated into an integral strategy directed towards improving on-site performance (Table 7).

Table 7: Performance Improvement Strategy for On-site Masonry Operations

<table>
<tr><th>Goals</th><th>1.Eliminate Defects</th><th>2. Minimise Waste</th><th>Support Processes</th></tr>
<tr><td>Actions</td><td>Revise design specifications with craftsmen.
Explain Seismic Code to workers.
Conduct Safety Workshops.
Implement visual-management tools.</td><td>Measure Waste.
Implement new transport and handling tools.
Identify loading, storage, and unloading locations.
New scaffolding equipment.</td><td rowspan="3">Motivate craftsmen to be like managers.

Conduct periodic learning workshops.

Incentivise a clean site layout.

Perform root-cause analyses.

Carry out periodic productivity assessments.</td></tr>
<tr><td>Goals</td><td>3. Implement Planning Techniques</td><td>4.Increase Productivity</td></tr>
<tr><td>Actions</td><td>Elaborate master plan through the line of balance.
Organise delivery of bricks and mortar through kanban-like signals
Implement visual-management tools to organise daily activities.
Start conducting weekly planning meetings.</td><td>Reduce non-contributory activities through i inventory and time buffers.
Standardise operations
Improve installation and assembly methods.
Start applying other Last Planner concepts.</td></tr>
</table>

The strategy does not pretend to be the ultimate plan for increasing productivity. However, the plan seeks to offer basic guidelines for correcting some errors and applying LC concepts. The strategy consists of five main components: four goals and support processes. Goals one and two do not require major changes and are focused on enhancing operations through employing visual-management signals and utilising new tools. Once these objectives have been accomplished, the company should seek to achieve goals three and four. These involve a greater management support because they necessitate applying production-planning techniques that are completely unknown for engineers and operatives. In any case, it is important for the construction firm to start using support processes (as described in Table 7) in order to generate a more collaborative on-site environment.

CONCLUSIONS

The paper proposed a strategy for starting to apply some basic LC concepts, such as, transparency, waste, and production planning. The suggested plan is based on the ideas expressed by authors, such as, Mitropoulos and Howell (2001) and Koskela et al. (2003). They claim that real change in construction should start by enhancing operational activities. Despite the fact that the company under analysis had not initially shown a real interest in applying LC ideas, the strategy was well received and actions related with the first two goals have started to be implemented. Further research is required in order to analyse how to accomplish the other two goals and how to link these initiatives with the firm's business objectives.

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