LEARNING, STRUCTURAL MASONRY TECHNOLOGY AND LEAN CONSTRUCTION: A CASE STUDY IN A SMALL BUILDING SITE

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ABSTRACT

This paper aims to analyze the learning processes of construction workers when they interact with new knowledge in the implementation of structural masonry in a lean environment. Specifically, mortar production control was established through the use of kanbans. Moreover workers have incorporated new techniques in the execution of structural masonry operations and lean principles as transparency, group working, prototyping and proper use of simple innovative tools. Site management took and active role in introducing an open minded atmosphere for communication and discussion in connection with new concepts that were taught. Learning occurs due to a new balance of coordination actions between engineer and workers. Thus, learning became part of production. There was a greater involvement of workers enhancing their ability to build up theoretical and practical knowledge that they deemed useful for the course of their professional lifes.

KEYWORDS

lean construction, learning, productivity, kanban

INTRODUCTION

Construction activity is booming in Brazil thanks to a growing economy and the expansion of housing finance. This attracts newcomer's developers to profit from the unusual market circumstances that are peaking after a stagnant period of more than 30 years. They do not bring any special expertise both in terms of technology and management assets and face a skilled manpower shortage. This made it possible and readily accepted by the board of a newly established construction company

to start using a lean construction approach to carry on work on a small building development of 2.094,98 sqm, 4 story height, with 416,90 sqm per floor and a total of 24 apartments. This took place from August 2010 to February 2012. This research work purports to describe how learning methodologies were employed to create a new work atmosphere in order to introduce masonry improved technologies based on modular coordination and lean principles.

This case based research might be of interest as it deals with a small building company undertaking just one building at a time, with no previous building experience, employing newly recruited semi-skilled manpower, with reading and numerical abilities hampered by a low level of formal education. Apparent success in

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the introduction of lean concepts, under these difficult circumstances, might be associated with the novelties of masonry modular coordination and lean management, easy going site managers, receptive workers, and a focus on learning rather than on productivity or cost savings. Workers perceived learning environment and new topics being introduced as a chance to improve their careers and benefit latter from the experience they were going through, despite pressures by company's directors to achieve high productivity, reduce costs, keep just to acceptable levels of workmanship and work on an individual basis rather than in group. Novelty struck also those directors, as they were not able to fully understand what was going on site and could not compare it with similar developments. Facing reduced options on how to strategically conduct this development, they ended up by leaving the site follow its own course, as directed by a newly hired lean trained site manager.

LEARNING IN ACTION

According to Hirota (2001), learning in action was first addressed by Revans in 1938 while conducting research to understand the interplay between physical abilities and intellectual proficiency that might be derived by the concomitant manual and conceptual effort to perform a task. In order to produce a clearer definition Pedler (1996) and Weinstein (1995) views are added noting that

> ¨action learning is a method for problem solving and group learning that aims to bring about changes in people, in groups and in the organization according to the first author, while the second emphasizes that it is a way to learn from the actions that are being enacted, if enough time is dedicated to questioning and reflecting on them, searching for new forms of analyzing existing problems and finding out better actions in the future".

The 2001 doctoral thesis by Hirota explores action learning in connection to lean management and makes the necessary literature survey on the psychological, epistemology, language, training and problem solving aspects that rooted this discipline in human behavior modification. As its main concern is related to construction activity work, two key issues were discussed as they are normally opposite to what is found in building sites: group discussions and free expression of uncertainty and doubts are antecedents to the action learning mechanism. She goes further by saying:

> " Learning at regular meetings consists of a small group of people addressing professional issues related to their activity, by means of sharing problems and experiences, questioning on going practices, clarifying doubtful points, wide spreading remarks on what is not known, seeking new knowledge, formulating ways to and implementing solutions, analyzing and reflecting on what has been achieved"

Maturana (2004) view is also brought forward in the sense that learning is typically an observational process. The observer is not anymore and outsider, trying to understand what others are doing or teaching. He is an active member of the process and its responsible both for operational outcomes and knowledge accumulation. According to the "observer involved Maturana's principle" a central part of promoting science and knowledge is the quest for understanding and reasoning men experience as a human being. Understanding can be equated to translating reflections about operational acts in a proper language, that is, assuring that something is known if it can be expressed through a common language. For the purposes of this research work, it might be anticipated how important is the dissemination and indoctrination of a lean vocabulary.

Finally, action learning requires a three stance attitude, namely being, knowing and doing. Nothing short of these three requirements acting in close sequences would enable long lasting change of behavior. Moreover, in order to address increasingly complex problems, practice should be accumulated in the process of acquiring knowledge and putting it into use. A better attitude towards learning would be the necessary testimony that a human being is changing and eager to promote new knowing and doing cycles.

Direct conversation between site engineers and the group of workers is the preferred media to promote action learning. It allows close observation on human behavior, on knowledge acquisition and provides support for experiencing new forms of doing. Formal workshops are also employed where site engineers, foreman and workers would try to express their learning in a more systematic way.

Two main subjects were addressed in this research work, namely masonry modular coordination and lean concepts, in order to maintain learning focused on a restricted number of issues. Action learning efforts spanned the whole duration of masonry activities, what took four months. No pressure was put in bringing new issues to the learning arena throughout this period and learning progress was acknowledge only when all workers taken as a group were able to master what was being taught in terms of a better way to pursue structural masonry construction.

A GENERAL VIEW ON THE BUILDING ENVIRONMENT

Foundations, ground floor and first floor reinforced concrete structures were already cast into place when it was decided to engage in lean construction activities due to the hiring of a new site engineer trained on the subject.

His first duty was to draw structural masonry modular coordinated rows of ceramic blocks that will constitute elevation walls for the next four stories. Three differently sized blocks where used: 14 cm x 14 cm x 19 cm, 29 cm x 14 cm x 19 cm and 44 cm x 14 cm x 19 cm. At that time, two major problems were anticipated: first that the reinforced concrete structure did not take into account that precise modular coordinated blocks would follow, thus careful ceramic block positioning was required to made up dimensional differences; second, to make things worse, there was no hope of hiring skilled bricklayers, with modular coordination skills to produce walls. Better management seemed to be the only way out of these two unfavorable circumstances.

Moreover, it was reckoned that structural masonry does not only require close attention to walls erection, but should be taken as a complete building system that will influence all work stages following bricklaying.

STRUCTURAL MASONRY AND MODULAR COORDINATION

Manzione (2004) maintains that structural masonry is a competitive construction system only if explored in full. It's potential for a high degree of building rationalization supports and organizes other building systems, like walls' coating, plumbing, electrical, windows and door hanging, ceiling and flooring. The system is built up on a single construction unit, the 29 x 14 x 19 block, with different blocks and concrete prefabricated elements as complementary components (what is called the 29 family of blocks). While setting a single block, every bricklayer is faced with the intellectual reasoning on how electric and plumbing conduits will run inside the wall, how electric and plumbing outlets will be positioned within the limits of each single block, how blocks alignment will contribute to a thinner rendering coat, how window and door dimensions will fit modular dimensions left for them and finally how ceiling and flooring screeding will be of an exact thickness in order to maintain precise internal heights for each apartment room.

It should be noted that structural masonry can be made simpler by the use, for example, of external electrical and plumbing conduits, removal of rendering coats or restricting the structural responsibility only to part of the walls. This was not the case for this building project, where it was decided to take full advantage of the structural masonry system, but maintaining conventional construction appearance. This is the reason why in most of Brazilian cases, electrical and plumbing installations run inside the walls.

Modular coordination is the last step in a rationalizing a building project. First building components should be standardized, that is they should be supplied on agreed dimensions and quality throughout the project duration. This represents a problem for ceramic blocks, since just a few producers are able to guarantee supply for long periods of time, and they charge a price for this. Second, dimensions should be coordinated according to any chosen metric standard (what is called dimensional coordination) and finally a specific metric standard, a module, is taken as the measuring unit (and hence modular coordination). Conventional building measures as indicated by the usual carpenter's scale are abandoned, as metrics are governed by module multiples (or submultiples). This proved to be a completely different way of working for those involved in the building trade, especially for the operatives engaged on the first steps of masonry construction.

Notwithstanding, the intellectual complexity of working this new method was made simple by two complimentary design and implementation efforts. The first two rows of blocks were carefully designed according to their exact positioning in a modular grid. Once it was solved the combinatorial design problem of finding how to best arrange the blocks along the walls, it is just a matter of repeating the exact configuration of these two first rows as many times as needed to make the wall height. A second recourse was to drawn the walls, one by one, with all rows of blocks, as shown in Figures 1 and 2. Such drawings were displayed near the working place.

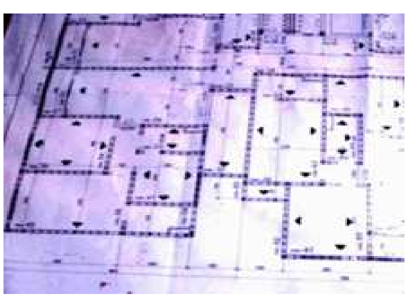

Figure 1: Plants of the first row

Figure 2: Masonry pagination

Ramalho and Correa (2004) insist that structural masonry can only achieve their fullest benefits in terms of rationalization and economy if modular coordination is strictly followed. The common recourse used in conventional masonry of cutting bricks to fill gaps and enlarging horizontal and vertical joints to overcome dimensional problems cannot be tolerated. This is a sort of waste to be banished by both good structural masonry workmanship and lean construction principles.

LEAN CONSTRUCTION

Simplicity might be associated with structural masonry, as a number of preceding and succeeding stages of work can be eliminated, like reinforced concrete beams and columns formwork, several coats for wall rendering, windows and doors fitting to the nominal spaces left for them. Variability can also be reduced due to the standard and precise size of blocks and the fact that walls execution should follow what was previously designed (the already mentioned working drawings - known as masonry pagination).

Apart from these lean principles that follow from the technology itself, this construction site experimented two organizational tools. First kanban signaling was used to order materials. Those in charge of supplying from external sources and commanding logistics on site did use a heijunka panel to find adequate sequences for materials' distribution. Figure 3 and 4 illustrate respectively kanbans and a heijunka panel as used on this construction venture. Second, just in time ordering of materials and execution of preceding work was enforced.

Figure 3: Kanbans.

Figure 4: Heijunka panel

Cellular arrangement of trades was made possible by both technology and management induced attitudes. It is common to install in parallel some reinforcement and plumbing pipes while erecting the walls. Apart from that, the number of different stages of work to produce the building structure and its enclosing is reduced when compared to conventional construction. This makes it easier for a single crew to perform all activities. Even so, site management insisted on group working, not allowing couples of bricklayers and their dedicated servants to carry on pieces of work at their will on an individual basis.

Both structural masonry and lean construction were combined to produce knowledge according to the following methodology.

LEARNING METHODOLOGY - IMPLEMENTATION STEPS

Step 1: Workers recruitment and selection

This was done by a joint effort to recruit skilled, unskilled workers and foreman in an specific moment in time. On a single day 15 workers were interviewed (including 3 foremen) and explanations were given on how site management was planning to conduct building operations on site. A short introductory course in structural masonry and lean concepts was delivered. Questions and answers were freely discussed. After that, workers were released to reflect on the possibility of embarking in this new and challenging job.

Only the ones that decided to stay for the next recruiting and selecting stages were further communicated about the building company structure, labor contracts, health and safety procedures safety and earnings. One foreman, 4 bricklayers and 3 laborers were finally included in the site payroll. None of them were experienced with structural masonry and lean concepts, despite the widespread awareness of Fortaleza building community on the latter concepts.

Step 2: Structural masonry implementation

As already mentioned, ground floor reinforced concrete structure was already cast and ready for further work on its top. This 450 sqm open space was taken as a laboratory, were experiences might be conducted, errors tolerated and whenever needed dismantling of blocks rows encouraged in order to pursue better workmanship.

During this stage, the site engineer acted as a coach, personally directing work on site. Every good workmanship detail or error was a motive for workers to get together and discuss what to learn from them. In parallel, the foreman was instructed by more formal means, like getting acquainted with wall working drawings, reading work instructions, seeing videos on structural masonry and reading professional literature. It was envisaged that the foreman will be responsible for quality and training while the whole group of workers, foreman and the site engineer would decide jointly about the pace of work, expected productivity, sequence of work and payments.

Step 3: Introduction of kanban signaling for mortar ordering

After technical aspects related to structural masonry were mastered, kanban ordering of mortar was introduced. Several examples were displayed through what is already firmly established in the building community of Fortaleza. Films were displayed and benchmarking through visits to lean practioners' sites was made available. A simpler heijunka like box was produced as exemplified in the general view of figure 6 with closer details depicted in figure 7. Six columns indicate mortar requests by each of the different bricklayers; requests could be placed, through the use of kanbans, at intervals of 30 minutes. The mortar cell production gang composed of one mixer operator and two laborers will deliver mortar batches at the time they were requested, directly to the demanding bricklayer at his working location. At the end of a working day, kanbans were collected at the site office to analyze bricklayer's production and consumption of mortar. Production data was immediately communicated to those involved in the following morning.

Step 4 – Improving site communications and technology hardware

At the operatives' request, a number of improvements were gradually introduced to the site. They make part of a collection of small, cheap, incremental, site born and easily adaptable tools, machines and organizational measures that are seen on brazilian sites striving to improve productivity, quality and easing operatives work in ergonomically terms. They are technical called small scale technical innovations.

A set of those small scale innovation were presented to the workers through photography, videos or even benchmarking site visits. Adopted small scale technological improvements are exemplified below.

- drawing board at gemba location, allowing workers to view and scrutinize architectural and structural plans (Figure 5);
- working drawings for each partition being erected, facing the wall and enabling workers to figure out how it will look after brickwork conclusion (as shown in figure 3);
- use of a 30 cm, 25mm diameter pipe for mortar spreading as substitute for the usual bricklayers trowel; adoption of this novel but rudimentary tool was proposed as a solution for diminishing mortar waste caused by conventional trowel. This novel tool is illustrated in figure 6.

Figure 5: Drawing board

Figure 6: Half pipe

At the time, the site engineer took the opportunity to produce a lecturer on the entire supply chain leading to the availability of sand, cement and water on site: he made the point that waste impacted not only what was occurring on site but all the previous efforts expanded down the aforementioned supply chain. Despite its obviousness, this presentation deeply impressed workers that were not acquainted with this expanded reasoning.

- Joint quality inspections by foreman and site engineer, an special event on site when workers would get together to discuss reasons for bad or good quality of work. Whenever possible work was stopped at error's spotting, making it clear that quality is precedent to productivity and attainment of due dates. A friendly environment tried to avoid blaming workers for bad workmanship, trying instead to identify training needs;
- Weekly meetings lasting one hour on Fridays: an easy going atmosphere near the weekend made it easy to discuss problems faced during the week and plan work and improvements for the future. The casual looking of the meeting

shown in figure 7 also gives testimony to the humble conditions of the site and their workers, what did not prevent lean implementation.

Figure 7: Weekly meeting

REFLECTIONS ON LEARNING

Simondon (1989) argues that technical objects are incorporated by human beings as extensions of their selves. They both become part of their universe and extend their living possibilities. He summarizes technology adoption through a techno-aesthetic approach: a new tool is beautiful in action if it adapts well to the body that operates it and amplify its structural character. This might be the case with the learning process here described. After some weeks of training and learning, structural masonry lean block laying looks natural, as it was something that was already into workers abilities and values.

Two main psychological issues were behind such developments. First the use of kanban put evidence that production was under control, and it could be measured in terms of productivity, sequence, consumption and most importantly, due payments for the workers efforts. Even if site management went to great lengths to easy production pressure on site, this is so an established practice in the construction sector, that workers found relief in operating a system that whenever needed will demonstrate their productive capabilities.

Second, trust started to develop among the different production cells. Faced with a new challenging work, both in terms of structural masonry and lean management, workers felt that the whole team was engaged. This was mostly evidenced by the fact that mortar batches were only supplied according to kanban orders, and the other way round, the mixing cell felt that mortar produced would be put in good use, with no waste. This simple exchange of compromises, running smoothly after some weeks, was enough to encourage new management developments on site.

Work was split in smaller lots or work packages. The first two rows of blocks in every floor were a special moment to reassure learning achievements from previous stories and also a guarantee that quality will be maintained if these initial rows were properly set. Figure 8 and 9 show the first two rows part of the work and material storage for the next rows. Masonry work in connection to the third up to the eighth row was taken as an easy job: workers themselves expected higher productivity on this stage, recognizing that from there on a different kind of masonry activity would take place. Scaffolding was put into place to build the ninth to up to the thirteenth rows.

This last part of the work was prudently taken as a more effort consuming and reasonably lengthy, due to work over the scaffold, security reasons and plumbing requirements. This is to say that not only materials were supplied in batches according to the different parts of work as described, but also that work was taken as different, even if all stages deal with the same blocks and mortar. A clear understanding on how work was really performed was incorporated in everyone's reasoning. A practical outcome was the extension of the batching practice to the external supplier of blocks, according to these three different stages, what easy cash flow requirements and stockyard logistics.

Figure 8: Work pakage

Figure 9: Material Package

Drawings were profusely displayed on site but a missing link was observed. There was no device to translate what was drawn to the real world. Operatives would normally accomplish this by trial and error, putting some blocks at one of the extreme concrete slab right corners, starting their masonry activities from there on. This is a condemned practice as setting out errors might accumulate throughout the rest of the slab. A new approach was suggested marking orthogonal axis by the middle of the slab, as shown in figures 10 and 11.

Figure 10: Orthogonal axes

Figure 11: Marking the masonry

At first workers quarreled with both site engineer and foreman that were responsible for this new approach, mistakenly arguing that errors would propagate in both directions to either side of the orthogonal axis. This is a clear unrealistic proposition originated from a psychological reaction to what is new. After some trials, trust was regained and further helped to introduce a new leveling device known as the German Level (figure 12).

Finally, an increase in worker's coordination abilities was observed as they face more complex situations. Waste management was taken as one of the major goals for the projects. In order to accomplish this objective, workers took a leading role not only in applying what they have learned on modular coordination and mortar ordering, but also in terms of better setting out as permitted by the orthogonal axis system and the use of the German Level. Moreover, they started to question the quality of ceramic blocks they were receiving and even the apartments layout that was not conducive to a rational use of modular coordinated building materials.

Figure 12:– German level

It might be said that learning took effect as intended: workers were at the end in a position to understand what they were doing, to propose new production and even to suggest better apartment's design arrangements. They had created new attitudes as a group, mainly related to trust development, openness to experimentation and coordination of resources. There was a positive atmosphere with workers willing to face even greater challenges during the rest of contractual period for this site development and after that, during their professional carriers. They felt as bricklayers capable of performing structural masonry work under a new management scenario provided by lean concepts.

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