EVALUATING BUILDING SYSTEMS BASED ON PRODUCTION PROCESS MANAGEMENT AND LEAN CONSTRUCTION CONCEPTS

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ABSTRACT

Production processes have been already the main subject of many researches on construction. However, the great majority of them do not consider the new concepts introduced by the new construction paradigm, called "lean construction".

This paper presents the development and the application of a method that considers the main principles of lean construction as qualifying characteristics for the development of performance criteria for the management of construction's production processes. The main goal of the method is to investigate the degree in which the design of building systems consider the lean construction principles through performance indicators, as well as to make possible to consider explicitly such principles in the development of new construction technologies.

KEY WORDS

Construction technology; production processes; lean construction.

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INTRODUCTION

Nowadays contractors can find many different technology options both in their local markets and abroad. In Brazil, for example, there are new imported products and even packages of products available that suggest significant technology changes in the local contractors' current building systems (Silva 1996). On the other hand, contractors may also develop their own construction technology through investments in research and training, and these technological options can range from changes in isolated items or techniques to changes in the currently used building system as a whole.

It is important, therefore, to adjust the technology features and strengths to the company's competitive priorities and vice-versa. Skinner (1969) identified some decision categories that can be considered in any operations strategy. Some of these decision categories are directly related to the intrinsic processes of production technologies, such as the equipment definitions category, labor characteristics category and the engineering used category (value and process analysis). On the other hand, technological definitions must also consider more generic aspects. These aspects are basically, product-market environment, the firms strategic goals, the firm's resources and national resources (Grant et al. 1991).

Another important issue related to the search for technological improvement is that innovation is essential for construction companies competitiveness (Betz 1987). In this respect, it is quite important to effectively know what actually happens in the company's production function and how the current technology works in order to allow an effective establishment of a continuous improvement program (Edosomwan 1989).

However, construction companies in Brazil usually do not properly assess either their current technology or new technologies available in the market, their features and their practical impacts (Silva 1996). Thus, it becomes quite difficult for them to plan, control, develop or choose a construction technology which would fit their competitive priorities, and which would be adequate for the reality of the firm and country and also, one which would allow an effective continuous improvement process to take place.

This fact may be related to a certain lack of understanding on how the production function works in construction. However, Koskela (1992) introduced some concepts and established some principles about the production function of construction. These concepts and principles to perceive construction as a net of cycling production flows that have conversion and non-conversion activities, as well as activities that add and activities that do not add value to the final product or sub-product.

Based on these lean construction concepts and principles and on some interviews with construction experts, a method to assess building systems' intrinsic processes (those that do not vary with product, site or any other specific project characteristic) was developed to help contractors decide about the technology which is most appropriate for them. This method faces only the processes' management issues. Thus it must be used together with other methods that evaluate the other aspects related to the technology, such as building performance issues (fire proofing, water proofing, noise, thermal performance, etc.) and environmental performance issues (the amount of energy used to build and the environmental nature of the used materials, recycling materials, etc.). Figure 1 illustrates what the method developed aims to assess about construction technologies and building systems.

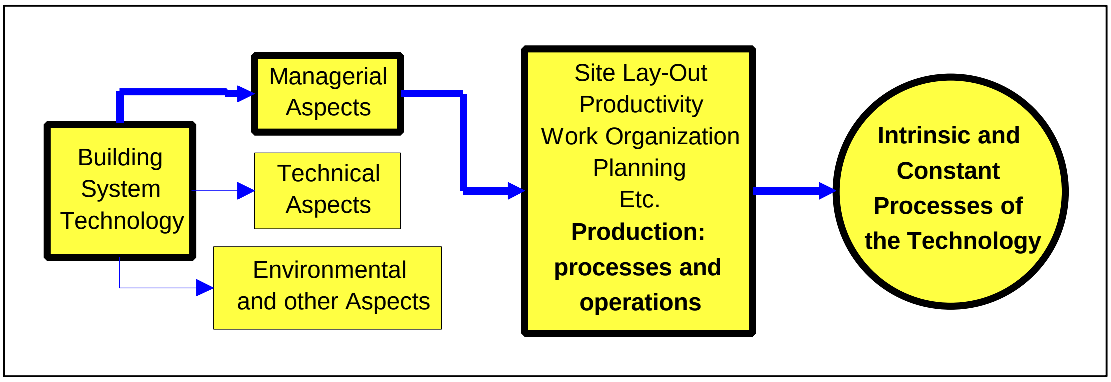

Figure 1: Object of Analysis of the Method

DEVELOPMENT STEPS OF THE METHOD

The first step in the research study was to identify which of the main principles of lean construction had a direct and measurable connection to production process management. As the proposed method had the challenge to evaluate only the technological influences of building systems on the production processes, no time and layout studies could be considered by the method's performance indicators. At this point, a number of interviews with construction management and building system experts were made as well as a number of brainstorming sessions with researchers and a thorough literature review about lean construction and related topics, in order to define the method's qualifying characteristics. These qualifying characteristics included most of the lean construction principles and some insights raised from other related production methodologies, such as Just in Time and Value Analysis.

The second step was to establish the performance requirements for production process management, which the building systems had to meet in order to "be lean". This was done based on an analysis of the performance qualifying characteristics proposed earlier. At this moment, a pilot study was performed on a construction site to assess the application of well known tools and techniques, such as the process chart, the VAT analysis, the precedence chart and others. The aim of this pilot study was to test these tools and techniques in practice and to identify which aspects of the proposed requirements were feasible to evaluate.

At the third stage, quantitative and qualitative indicators were finally developed These indicators aim to measure the fulfillment of the requirements. However, their development had consider the feasibility of their later measurement and data collecting impositions, which limited them to encompass all the aspects of the established requirements. Table 1 lists the prioritized performance requirements and the proposed indicators.

DESCRIPTION OF PERFORMANCE INDICATORS AND APPLICATION NOTES

The developed Method requires an evaluation phase which involves: (a) to produce a precedence chart for the building system processes; (b) to apply nine performance indicators, and to interpret the results of these indicators considering the principles of lean construction and the company's competitive environment.

Table 1: Established Requirements and Proposed Performance Indicators

Performance requirements for the evaluation of Building systems	Proposed performance indicators
- Reduce number of steps of production on site; - Use elements with greater value-adding rate; - Reduce the cycle time; - Minimize interdependence between activities; - Increase production flexibility (volume and services); - Reduce production lot sizes; - Standardize components and working methods; - Use multi-skilled craftworkers; - Provide work safety and ergonomy; - Establish joint ventures with main suppliers.	- Building system process design efficiency; - Production flexibility; - *Interdependence degree of system processes* - *Labor required skills* - Building system supply chain dependency degree; - Building system degree of material diversity; - Building system standardization degree; - Production externalization degree; - Maximum weight of components.

This section briefly explains the process precedence chart and the proposed indicators.

PROCESS PRECEDENCE CHART

Since no time and layout data is relevant for the evaluation of the technology intrinsic processes, a specific process chart has to be constructed each time this method is applied. This process precedence chart must represent an ideal performance of the technology's intrinsic processes in terms of precedence relationships. In most cases this ideal situation will never be realized. Moreover, this precedence chart must be constructed on a sheet with lines and columns that are respectively called "production levels" and "production lines". The process activities are represented by squares and their precedence connection by arrows. Besides, no lay-out data can be assigned to the method's application, some intrinsic transportation activities or waiting activities can be considered in this precedence chart as another "production level." Figure 2 shows an example.

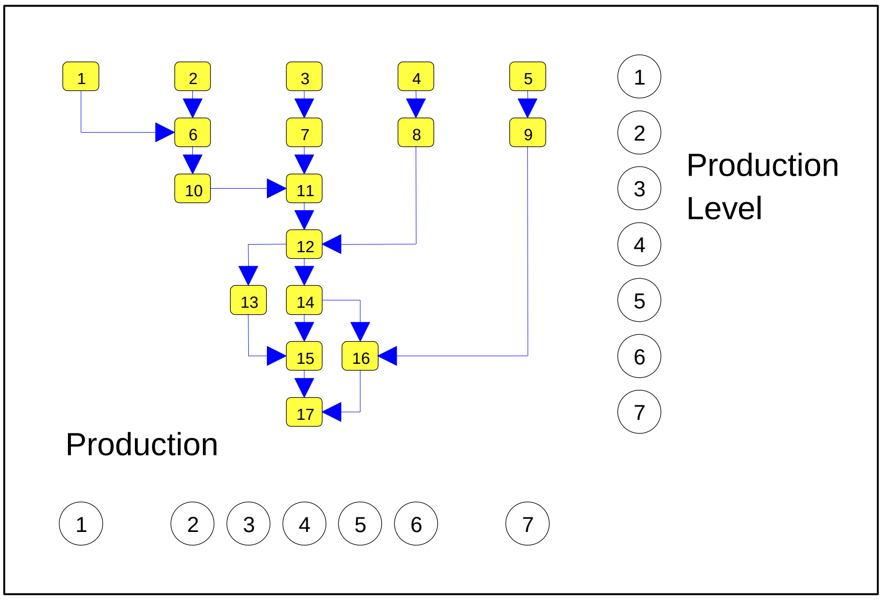

Figure 2: Example Process Precedence Chart

As the construction of this chart is rather laborious, it is advised to limit the evaluation to a certain repetitive group of processes. These can be, for example, related to one storey, one wall, one door, etc. The evaluation will depend on how the new building system or the new technology relates to a previously evaluated one.

PERFORMANCE INDICATORS

Nine performance indicators are proposed by the developed method. Below there are some brief explanations about their meaning.

Building System Process Design Efficiency

This indicator measures the number of steps the technology requires and its relation to the number of processes that the technology allows to be taken at the same precedence level. This allows quantifying the extent in which the intrinsic processes can be carried out simultaneously to the total steps required. Reducing the number of steps and simplification are some performance requirements that have to do with this indicator. The reduction of cycle time is another requirement that can be evaluated by this indicator. One represents the highest efficiency a building system can achieve in terms of process precedence design. Zero corresponds to the lowest efficiency. The formula below calculates the indicator. The input information can be gathered from the process precedence chart.

$$PDE = 1 - \frac{\sum_{i=1}^{n}\left(\frac{1}{\text{n}^{\text{o}}\text{ of lines of production level i}}\right)}{\text{n}} \qquad \text{n} = \text{n}^{\text{o}}\text{ levels of production}$$

Production Flexibility

This indicator measures the process precedence chart ability to allow changes in its optimal structure without changing the total number of production levels. Basically, it establishes a relationship between the total number of production levels of the precedence chart and the total number of production levels that are “adjustable”. These “adjustable” levels are the production levels where some sub-process of the production chain can be done, allowing some flexibility for the working teams or for material supply. It also measures the flexibility of the technology in terms of customizing the final product as late as possible. In figure 2, for example, process number 9 has 3 adjustable production levels of flexibility, since it only comes before process number 16.

This indicator ranges from zero to one, and the value one represents the most flexible technology possible. Its formula is as follows:

$$PF = 1 - \frac{\sum(\text{Number of production levels})}{1 + \sum(\text{Adjustable production levels})}$$

Interdependence Degree of System Processes

This indicator measures in relative terms the number of interfaces between the processes of the building system. First it combines the total number of processes identified in the production precedence chart with the total number of linkages between them. It has a strong relationship with the lean construction principle of simplification. Again, the value one represents no interdependence between processes, and the value zero represents as many interdependencies as possible. The formula below calculates the indicator:

$$ID = 1 - \frac{\sum(\text{Linkages between the identified production processes in the precedence chart})}{\sum(\text{Total number of identified processes in the precedence chart})}$$

Labor Required Skills

This qualitative indicator classifies the operations required by the intrinsic production processes identified in the analyzed technology in five categories that range from low to very high required skills (transportation, location, conformation, adjustment and finishing). It is another dimension of process analysis that is very important for the technological definition.

Building System Supply Chain Dependency Degree

This indicator predicts the difficulties that the production processes might have, due to heavy dependency on materials that can be distributed by few suppliers. It also helps to identify the degree of necessity to form joint ventures with specific suppliers. Its measurement requires the assessment of the most expensive materials that must necessarily be used in intrinsic processes of the analyzed technology. The value of the indicator is simply the total number of materials that represents about 75% of the standard project total costs and, on the other hand, do not represent more than 20% of the total number of different materials of the standard project cost estimate. This guarantees that the intrinsic materials are also financially importance and are worth making a joint venture to prevent problems.

This indicator must be applied considering not only the technology, but also environmental issues, such as the prices of materials and the standard project characteristics.

Building System Degree of Material Diversity

The management of the materials supply in the construction processes must be as simple as possible. If the building system requires too many different materials, it becomes more difficult to manage the negotiations with suppliers. Thus, the building system processes also become more susceptible to problems due to material delays and so on. This indicator tries to measure this susceptibility by counting the total number of different materials used in all the intrinsic processes identified and the total number of processes identified in the constructed precedence chart. The value one means that the building system is not like to be susceptible to problems with materials supply, and the value zero means the opposite. The indicator can be calculated by the formula:

$$\mathrm{DMD} = 1 - \frac{\sum(\text{processes identified in the precedence chart})}{\sum(\text{different materials used in the processes of the precedence chart})}$$

Building System Standardization Degree

This indicator measures the number of standardized sub-elements and processes of the analyzed building system process precedence chart and relates them respectively to the total number of sub-elements and processes of the same precedence chart. Value one means that all the processes and sub-elements are standardized, and value zero means the opposite.

Production Externalization Degree

This indicator measures the number of processes performed outside the final sub-element's definitive place, and relates it to the total number of processes of the building system process precedence chart.

Maximum Weight of Components

Another issue that must be evaluated is the weight and readiness of movement and transportation of the system's sub-elements that aren't produced at their definitive usage place. This measure is qualitative and indicates how easy the production operations can be done, giving an idea of the equipment needed to operate the systems' materials and it also gives an idea of the work safety of the analyzed technology.

APPLICATION OF THE METHOD

This method can be applied to any building system at any time. The information needed to construct the process precedence chart can be gathered from videotaping, photographing, observing what happens on the site and applying questionnaires to the system's designer or manager. Other informations are usually available in the standard project cost estimate. If the new technology or building system has not been used yet, the information required can be obtained from a detailed examination of the technology plans or designs, and a hypothetical standard project cost estimate may help with the other informations also.

RESULTS OF THE METHOD'S APPLICATION ON A BUILDING SYSTEM IN BRAZIL

The method developed was applied to a mass dwelling building system currently used in Brazil. The necessary data was obtained from the firm's specialists and from a site analysis. Data sheets and interviews were used, and a process chart addressing the whole construction processes of the analyzed building system was constructed. The results for the method's indicators are the following:

- Building system process design efficiency: 0,66;
- Production flexibility: 0,37;
- Interdependence degree of system processes: 0,75
- Labor required skills: 35 transportation operations, 13 location operations, 12 conformation operations, 16 adjustment operations and 19 finishing operations;
- Building system supply chain dependency degree: 5 (precast slabs, ceramic bricks, cement, finished windows and finished doors);
- Building system degree of material diversity: 0,86.

These results were interpreted together with the principles of lean construction. Some comparisons between a formerly used building system and the currently used one at the same construction company were also performed based on these results. Table 2 summarizes this comparison considering four competitive priorities: cost, delivery time, flexibility and innovation (Contador 1995). The indicatives ("better" or "worse") mean the current used building system performance in relation to the formerly used one.

Table 2: Comparison between the two Analyzed Technologies

Indicator	**Cost**	**Delivery Time**	**Flexibility**	**Innovation**
Process Design Efficiency	Better	Better	Worse	Worse
Production Flexibility	Better	Better	Better	Better
Interdependence Degree	Better	Better	Better	Better
Degree of Material Diversity	Better	Better	-----	Worse
Supply Chain Dependency Degree	Worse	Worse	Worse	Worse
Labor Required Skills	Equal	----	----	Equal
Standardization Degree	Not Observed	Not Observed	Not Observed	Not Observed
Externalization Degree	Not Observed	Not Observed	Not Observed	Not Observed

FINAL COMMENTS

The definition of the technology to be used by means of production processes may actually be aided with the application of the method presented, considering the company's competitive priorities. Therefore, many important aspects related to production processes were not considered in the method due to their linkage to site, project characteristics and other issues that are not specified by the technology used, but by the particular conditions and constraints of each project. Time and layout analysis are examples of these unconsidered aspects.

Moreover, the proposed method is not thoroughly completed, and other indicators may be developed in the future. These new indicators may in some way take into account the unconsidered aspects mentioned above.

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