Automation in Construction 19 (2010) 641–655

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Requirements for building information modeling based lean production management systems for construction

Rafael Sacks [b,*], Milan Radosavljevic [a], Ronen Barak [b]

[a] School of Construction Management and Engineering, University of Reading, Reading, UK
[b] Faculty of Civil and Env. Eng., Technion – Israel Institute of Technology, Haifa, Israel

ARTICLE INFO

Article history:
Accepted 24 February 2010

Keywords:
Building information modeling
Lean construction
Process visualization
Production control
KanBIM

ABSTRACT

Smooth flow of production in construction is hampered by disparity between individual trade teams' goals and the goals of stable production flow for the project as a whole. This is exacerbated by the difficulty of visualizing the flow of work in a construction project. While the addresses some of the issues in Building information modeling provides a powerful platform for visualizing work flow in control systems that also enable pull flow and deeper collaboration between teams on and off site. The requirements for implementation of a BIM-enabled pull flow construction management software system based on the Last Planner System™, called 'KanBIM', have been specified, and a set of functional mock-ups of the proposed system has been implemented and evaluated in a series of three focus group workshops. The requirements cover the areas of maintenance of work flow stability, enabling negotiation and commitment between teams, lean production planning with sophisticated pull flow control, and effective communication and visualization of flow. The evaluation results show that the system holds the potential to improve work flow and reduce waste by providing both process and product visualization at the work face.

1. Introduction

Construction projects typically involve multiple discrete organizations working simultaneously on congested sites. They suffer from waste that is manifested in waiting time for crews, rework, unnecessary movement and handling of materials, unused inventories of workspaces and of materials, etc. Achieving smooth work flow with minimal waste requires not only appropriate construction planning, but also effective production management.

Lean thinking applied to construction has led to development of planning and control systems and other practices that improve matters. Koskela's 'Transformation-Flow-Value' (TFV) conceptualization of production in construction [1] provides a theoretical basis for appreciating the flow and value aspects of construction in addition to the well established transformation view. Applied research using discrete event simulation has clearly shown the adverse impact of variation in production and delivery rates [2,3] and the benefits of pull flow of trade teams according to information maturity [4].

In practice, the Last Planner System™ (LPS) [5] and adaptations of it are increasingly applied to reduce variation, improve coordination and work flow, and thus to reduce various forms of waste in construction projects. While a detailed explanation of the LPS is beyond the scope of this paper, we list the principles that underpin it as they are the foundation for much of what follows. Koskela [6] outlined five principles for a production control system:

- assignments should be sound regarding their prerequisites (i.e. constraints must be released)
- the realization of assignments is measured and monitored (in LPS the percent plan complete measure serves this purpose)
- causes for non-realization are investigated and those causes are removed
- a buffer of unassigned tasks which are sound for each crew is maintained
- in look ahead planning, the prerequisites of upcoming assignments are actively made ready.

In his definitive work on the LPS [5], Ballard added the following:

- Variability must be mitigated and remaining variability managed
- The traditional schedule-push system is supplemented with pull techniques
- Production control facilitates work flow and value generation
- The project is conceived as a temporary production system
- Decision making is distributed in production control systems
- Production control resists the tendency toward local sub-optimization.

The LPS was designed to be applied with minimal, if any, information technology support. Nevertheless, effective production management in construction projects with large numbers of essentially independent work teams and extensive distinct spaces (such as office towers,

* Corresponding author.
E-mail addresses: cvsacks@techunix.technion.ac.il (R. Sacks), m.radosavljevic@reading.ac.uk (M. Radosavljevic), ronen@rbarak.com (R. Barak).

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doi:10.1016/j.autcon.2010.02.010

shopping malls, etc.) remains difficult to achieve. A number of factors make coordination between the trade contractor teams, material and equipment suppliers, construction management personnel, and designers and inspectors difficult. Among them:

- physical dispersion of the teams within the building or across the site, where they are usually hidden from one another by the structure itself;
- contracting relationships with remuneration terms that encourage local optimization and work against overall project optimization [7];
- complex variations in productivity rates [8], which makes it very difficult to predict short-term progress;
- lack of effective real-time reporting of progress, despite multiple research efforts aimed at automating this aspect of project control [9];
- dependence on key individuals to obtain and communicate critical information regarding constraint status to the look ahead and last planner functions;
- reliance on paper documents to communicate product information, with the limitations of design documentation errors, lack of clarity and potential obsolescence of information [10];

While the LPS reduces variation by improving the reliability of short-term planning, it does not achieve pull flow in the pure sense in that it does not prioritize tasks in relation to signals from downstream demand. In lean production in manufacturing settings, pull flow is implemented using 'Kanban' systems [11]. In manufacturing plants, process visualizations are used to provide flow signals to workers and to empower them to adjust flow to suit the overall system pace [12]. On construction sites, where work teams, not products, move, it is very difficult to visualize the flow of the work in progress and to communicate its status to the teams and individuals involved. The amount of buffered work in progress (WIP) accumulated between work teams cannot be seen by the naked eye in the same way that piles of products that constitute WIP can be seen accumulating between processing stations in a manufacturing plant [13].

Another problem is that the most common cycle time used with the LPS is one week (called 'weekly work planning'). The weekly response time is too long to avoid waste in the case of tasks whose constraints are only resolved within days prior to their execution. For example, the maturity of building finishing works that have short task durations and multiple and varying dependencies on information, preceding tasks and equipment, cannot be guaranteed in advance of a one-week window. Where the LPS is used with a shorter planning window (e.g. [14]), it has been done on projects where work is narrowly focused and all participants can easily see the process status, unlike the case of finishing works in large buildings.

Finally, as implemented in practice, the weekly work plans do not make any *a priori* provision for structured experimentation that could facilitate continuous improvements; rather, the percent plan complete measure is compiled, which enables retrospective learning from failure, but not planned learning from success. Although the formulators of the LPS envisioned that it would support learning from success, the pressures of day-to-day construction make recording of success for learning (both within and beyond the current project) impractical. A computerized system with automated recording and reporting might obviate this difficulty.

To address these issues, we propose that production management systems for construction should be based on BIM platforms and introduce Kanban style pull process flow and Andon alerts. We call this concept 'KanBIM'. We hypothesize that a software system that supplements the LPS by providing ubiquitous access to 3D visualizations of process status and future direction, delivered to all on site and enabling real-time feedback of process status, including Kanban card type pull flow control signals and Andon alerts, can empower people to manage the day-to-day flow of construction operations with greater reliability and less variability than can be achieved without such a system. The following sections of this paper outline the state of the art, describe the goals and method of a research program underway to develop the KanBIM concept, and establish the requirements for the modes of operation of future KanBIM type software systems.

2. State of the art in software systems for production management in construction

With few notable exceptions, most of the academic and industrial research on computer-aided design and visualization in construction deals with building design and with pre-construction planning. There has been far less effort to develop Building Information Modeling (BIM) based tools to support coherent production management on site.

The 4D CAD concept [15] has been implemented commercially in dedicated construction planning software (such as CommonPoint [16] and Synchro [17]) and has also been incorporated in fully-fledged BIM tools. Akinci et al. [18] demonstrated how work spaces and temporary facilities could be generated and added to 3D building design models to enable evaluation of construction plans for space conflicts. Some systems incorporate cost as a 'fifth dimension' of project information and aim to enable 'virtual construction' [19]. These are appropriate for pre-construction planning and monitoring schedules, but not for day-to-day production management, because they do not support fine-grained collaborative task negotiation and planning between teams, their displays are not intended for work crews on site, they do not support pull flow control, they do not support explicit checking and removal of constraints, and they do not define activities with sufficient degrees of detail.

Songer et al. [30] proposed to integrate workflow modeling with 3D CAD to enable visualization of project performance. Two examples of software that implement lean construction flow control, but do not use building models to support visualization, are Choo et al.'s [20] 'WorkPlan' system, which applied a database of work packages and constraints to support the Last Planner System process, and SPS, a commercial package that helps reduce supply chain variations [21].

The Lean Enterprise Web-based Information System (LEWIS) proposed by Sripresert and Dawood [22] is a sophisticated integration of a building model, a decision support system that performs optimization of construction plans using an evolutionary algorithm, and 4D visualization delivered on a web-based and mobile information management system. It is rooted in the LPS approach in so far as it aims to enable generation of reliable plans and constraint-free execution assignments. The implementation included graphical depiction of constraints, such as material deliveries, by color-coding objects in a building model view. ConstructSim [23] is a commercial software package which offers model-based work planning (including detailing master plan level activities into detailed 'work packs' for fine-grained production planning), constraint checking by associating building model objects with external supply chain information systems, and visualization of project and work status by color-coding of model objects. Both LEWIS and ConstrucSim fulfill a number of the requirements defined in this paper, but both stop short of direct engagement of the 'last planners' (the trade managers and crew leaders) themselves in operating the system. Their interfaces are designed to be operated by engineering management. Neither system provides explicit support for online negotiation of weekly work plans, nor does it support explicit pull flow control. Their process status and forecast visualization are product-centric, in that they make the progression of production visible by displaying the current and future states of the building or plant, but do not explicitly show the locations of work teams or work in progress. TOKMO [24] is a more advanced commercial system, but it too is primarily a desktop solution that does not deal with the dynamics of day-to-day information delivery and reporting at the workface itself.

An earlier attempt to address these shortcomings, particularly the need to make the project status, not only the product status, visible, used a reporting interface that incorporated symbols akin to traffic signs [25] (see Fig. 1). It was developed to communicate project status to finishing works sub-contractors for a shopping mall project, and