

KanBIM Workflow Management System: Prototype implementation and field testing

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Abstract

Research Question: can a BIM-based workflow information system help construction personnel implement lean pull flow strategies? If so, how, and to what extent?

Purpose: to test a prototype system in the field, measure and monitor its impact, and evaluate and discuss the implications.

Research Method: we have implemented an early prototype of a novel workflow management information system for construction, called 'KanBIM', and tested it on a large residential construction site in three stages.

Findings: the main significance of the results lies in the site personnel's positive experience with the system and their observations of the ways in which it could influence the behavior and productivity of crews. These included recognition of the effect the system had in encouraging well-informed discussion and negotiation between crews concerning coordination of work.

Limitations: although PPC and other quantitative measures were collected, the duration of the field tests and the depth of integration in company information systems insufficient to provide conclusive results.

Implications: while the results are positive and indicate the value of BIM-enabled process flow control, further development and testing is needed.

Value for researchers and practitioners: the prototype and the findings are an essential guide for future development of lean process flow control systems. We identify specific benefits a full implementation could bring to subcontractor trade managers, superintendents and other project management functions.

Keywords: information systems; building information modeling; lean construction; production control; process visualization; field trials

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Introduction

Analysis of the synergies between lean construction and Building Information Modeling (BIM) (Sacks, Koskela et al. 2010) has revealed that there are a number of areas in which the high quality of **product** information provided by information modeling can have a positive effect in improving the flow of work on site. These include reduction of design and fabrication cycle times, reduction of rework, and improved reliability of material and other quantity information. Earlier research produced promising results concerning the effectiveness of building model based interfaces in delivering highly visual representations of the current and future status of the **process** aspects of construction projects (Sacks, Radosavljevic et al. 2010). Visualizations of flow and of production status, such as ANDON signals, have been used to good effect in lean implementations (Liker 2003).

At the same time, there is a growing recognition on the part of many practitioners and researchers that despite the clear benefits of the Last Planner[®] System (LPS) (Ballard 2000), implementing it in construction organizations over the long-term requires significant support for project teams by dedicated LPS[®] facilitators and/or a relatively deep learning process for all the personnel involved in any given project (Bortolazza, Costa et al. 2005). Such levels of support are difficult to maintain, but in their absence teams tend to revert to traditional practices (Leigard and Pesonen 2010). Software systems that implement a specific workflow facilitate process change across and between organizations even where the motivations for the new workflow are not entirely understood by all of its participants, because, coupled with appropriate changes to commercial contract terms, they provide a framework for conformance to the new process (Riezebos, Klingenberg et al. 2009). Davenport and Short (1990) detailed the mechanisms of the interactions between business process change and information technology, highlighting the recursive nature of the relationship between the two, where the one supports the other.

The apparent effectiveness of information systems in supporting lasting changes to workflows, coupled with the powerful information visualization capabilities of BIM, led us to hypothesize that a BIM-based workflow information system could help construction personnel implement lean practices. We specifically pose the question in regard to the potential for guiding crews to pursue work according to pull flow strategies, because they are highly effective but challenging to implement (Brodetskaia 2012).

The research method was to develop and test a prototype experimental management information system comprising procedures, software and hardware designed to support lean work flow control on construction sites. The system, called 'KanBIM', facilitates short-term work planning and monitoring, providing clear visualization of the maturity⁴ of tasks planned and the status of work under way. The term 'KanBIM' (Kanban using BIM) refers to lean construction principles and to building information technology (BIM). 'Kanban' is the Japanese term for cards used to operate pull flow control on lean production lines (Hopp and Spearman 1996; Liker 2003). In construction, Kanban systems have been implemented for buildings (Pereira 1998), for heavy civil projects (Jang and Kim 2007) and for supply of materials (Arbulu, Ballard et al. 2003; Arbulu, Koerckel et al.

⁴ The term 'maturity' is synonymous in this context with 'soundness'.

2005). BIM refers to the process of compiling parametric object-oriented 3D computer models of buildings and to the various technologies used to compile and exploit them (Eastman, Teicholz et al. 2011).

The research aimed to make an initial assessment of the ways in which such a system can help construction personnel implement lean pull flow strategies, and to collect assessments of existing and missing functionality from potential users. We developed prototype software, sufficient at least for experimentation on site, and tested it in incremental steps through which it was improved and tested further. The scope of the prototype for the field tests was restricted to the Team Leader's Interface and the Product and Process Status Model, which will be detailed below. The field tests were carried out in three stages, each of which consisted of a weekly work planning meeting and a full week of observations on the construction site of a high-rise apartment building.

Information systems at the work face

The notion of bringing information directly to the work face at a construction site is not new. Hewage and Ruwanpura (2009) tested an 'information booth' which provided workers access to construction drawings. This was restricted, however, to design information delivered in 2D. The LEWIS research prototype system (Lean Enterprise Web-based Information System) (Sriprasert and Dawood 2003) and the ConstructSIM commercial software (Bentley 2005) both have model-based construction planning functionality, constraint checking and visualization of work progress. Neither, however, fulfill all of the requirements defined for the KanBIM system (listed in the following section), primarily because their system logic was designed to be used by engineers, not by the crew leaders and workers on site. As such they lack the facilities for the crew leaders to access information or to update process status directly from the work face.

On the other hand, integrated solutions, such as Tekla and Vela's field software solution that is delivered on handheld tablet PCs (Sawyer 2008), do bring the information to the workforce and include BIM models, but they do not support negotiation of planning and explicit registration of commitments as called for in the LPS[®]. For a thorough review of the state of the art in research and commercial software systems for production management in construction, including tools for monitoring progress, please see Sacks et al. (2010).

KanBIM Prototype Development

The functional requirements for development of the KanBIM[™] system have been classified under seven main headings (Sacks, Radosavljevic et al. 2010):

- Process visualization
- Product and method visualization
- Computation and display of work package and task maturity
- Support for planning, negotiation, commitment and status feedback
- Implement pull flow control
- Maintain work flow and plan stability
- Formalize experimentation for continuous improvement

Fulfilling the KanBIM system's functionality requirements requires a system architecture that defines the interrelationships between the building information model on which the system's databases are founded, the multiple user interfaces, the external information systems with which it communicates and the information brokers that implement the communication.

Figure 1 provides a high-level view of the system architecture. At the heart of the system lies the main database which contains the federated building model at a construction level of detail. The model contains interrelated information from the product model that results from design and fabrication detailing; the process model, which is populated by applying construction methods, aggregating objects for association with work packages and generating model objects to represent temporary equipment; and the status model, which defines the planned, current and as-made status of work packages. After initially compiling the model, the construction BIM modeler is responsible for synchronization of the database with any changes to the design and fabrication models.

Interaction between the KanBIM users and the construction model is facilitated by different user interfaces, such as look ahead planning, weekly plan preparation, weekly work planning and negotiation, a crew leaders' interface for delivering information and reporting status (Figure 2) and an alert system to support organizational workflow. The first three conform to LPS[®] process steps. They facilitate definition of work packages by associating them with groups of product model objects, as well as filtering of work packages for soundness, managing the workable backlog, and assignment of work packages in weekly work planning.

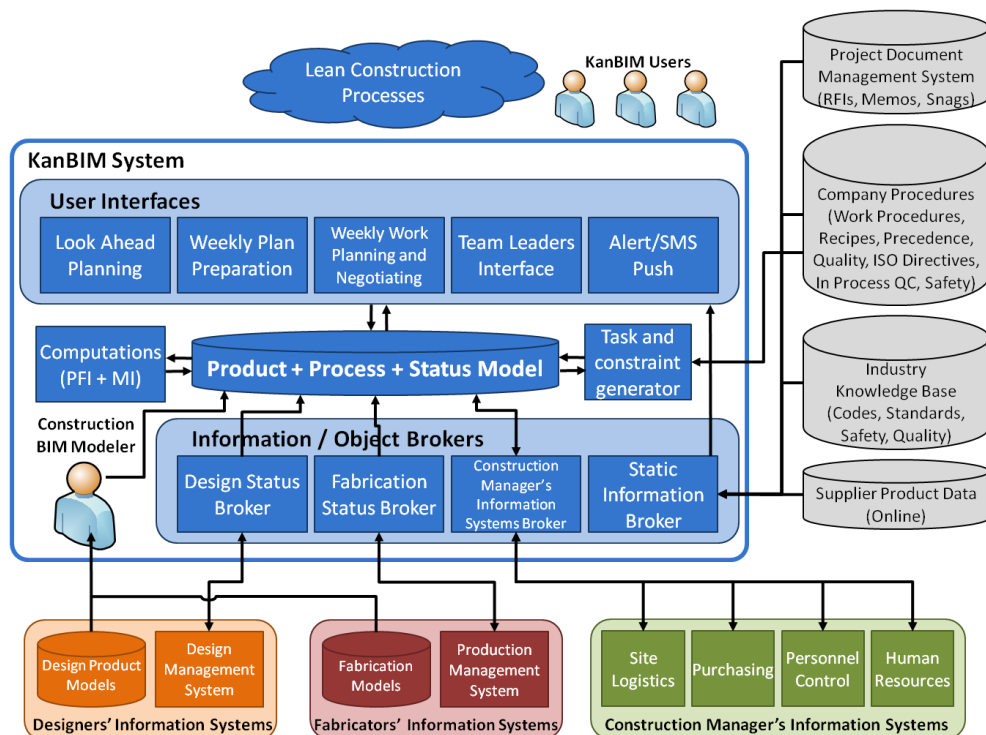


Figure 1: System architecture chart

Two computational modules work in the background. The first generates tasks and constraints at a detailed level, based on the typical constraint relationships defined for the

work packages from which the tasks are created. The second computes the current values of the pull flow index (PFI) and the maturity index (MI) for each task at all times and propagates them to the different interfaces (for definitions of these measures, please see Sacks, Radosavljevic et al. 2010).

The sources of the information the system requires extend beyond the boundaries of the construction product and process model and may reside in different peripheral construction management systems, such as logistics, purchasing, human resources and personnel control, design management systems, fabrication management systems and external databases. Reaching the right piece of information demands sophisticated information or object brokers, and because every system has its own business logic these brokers need to be unique to match the source systems they address.

The user interface (Figure 2) is used for all interactions with both the process data and the 3D model. That includes filtering through task assignments, selecting and zooming to tasks as well as reporting starting, stopping and completing tasks. The user interface was provided in four languages (English, Hebrew, Russian and Mandarin Chinese) to facilitate its use by the different groups of workers on the construction site where the field experiments were conducted.

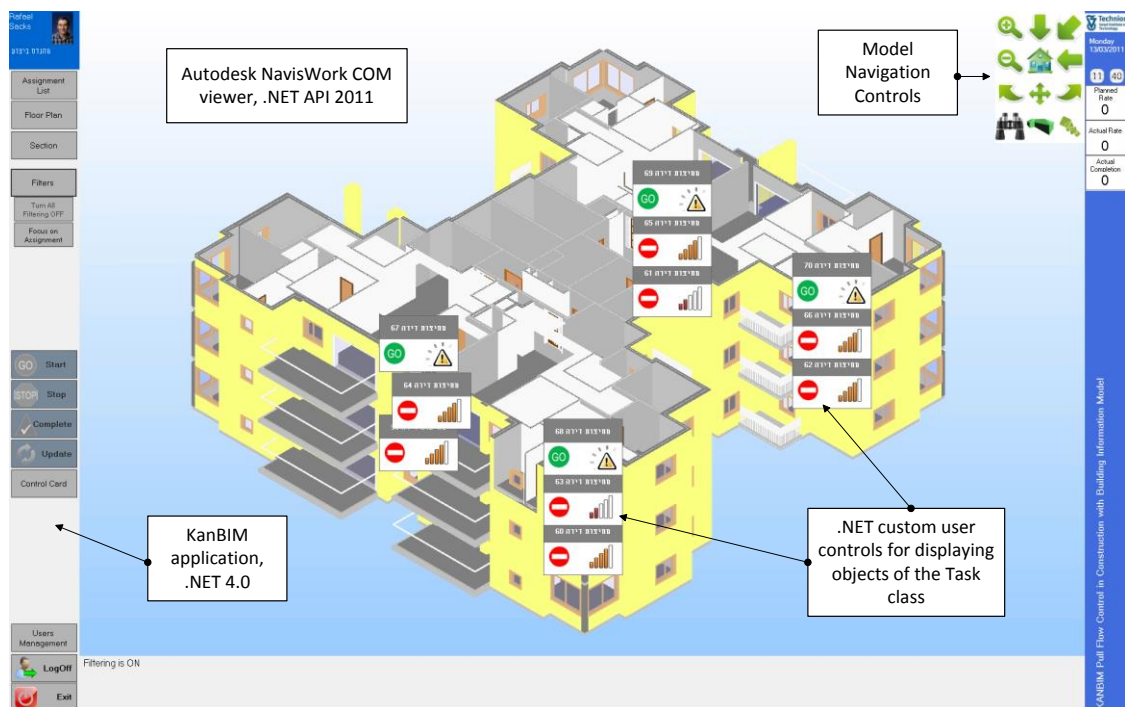


Figure 2: KanBIM primary interface, showing the .NET 4.0 application, the embedded Navisworks COM viewer, the custom task controls overlaid on the model, and the model navigation controls.

The two primary services the interface provides are to inform users of the status of the process and to allow them to input changes to the process status. Status information is delivered in the form of 'task labels' or controls, which represent all of a team leader's tasks that are scheduled to start in the current weekly work plan, tasks that are in progress, recently completed tasks, and any tasks that had to be stopped prematurely.

Each task also has a control card that can be opened to display information about the task's precedents: the space where the work is to be done, the tasks which must be completed before the current task can start, the location and availability of materials and equipment, information about design changes, and updated drawings.

A user can perform three actions on tasks to update their status, as summarized in the flowchart shown in Figure 3. In order to start a task, the user would select the task, click on the start button, and then expressly confirm his/her commitment to completing the task as planned. Once the task is committed to, its status changes to 'work-in-progress'. If a problem should occur that prevents a crew from completing a task, the stoppage should be reported by selecting the task and clicking the Stop button. The final action for a task is to report its completion.

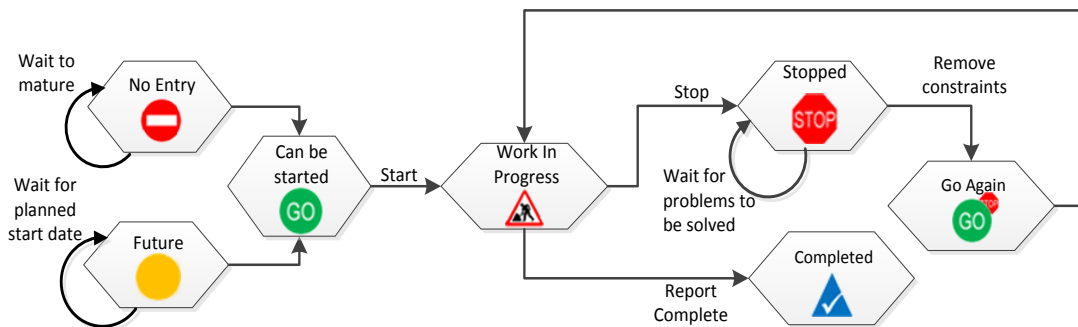


Figure 3: KanBIM™ task status cycle

Fulfilling the KanBIM Principles

Despite the best efforts of project managers and planning teams, the uncertainty inherent in construction operations results in changes to work plans. To avoid propagating plan failure and the associated waste within the current planning phase (usually a week), trade managers and trade crew leaders need both a) to be continuously informed of the current status of operations, and b) to have the ability to proactively change daily task assignments in close coordination with all parties that may be affected by the change. During planning of each upcoming week, each task is presented to trade managers and project planners with a set of symbols and text, as shown in Figure 4, which includes task name, trade symbol, current maturity index and the pull flow index.

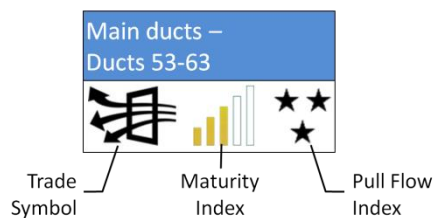









Figure 4: Task label

During plan execution, current status visualization is attained using the set of graphical symbols described in Table 1. The symbols describe the current task status: ready, not ready, task in progress, task stopped, etc. Symbols that represent deviation from plan are supplemented with additional information, such as maturity level or partial completion indicator. For these tasks, a user can investigate further by entering the

control card and examining detailed real-time task information. The symbols are also buttons that report action: tasks that are ready can be started and those in progress can be updated, completed or stopped. When reporting problems, a use can communicate directly with those responsible for any particular constraint, such as other crew leaders or a site logistics manager.

The BIM model is the foundation of the KanBIM system database. A 3D model view serves as a background platform in all interfaces for conveying project data and navigating through it, as can be seen in Figure 5. The challenge is to make product and process information ubiquitous at the workface without encumbering crew leaders or workers with hardware that may hamper their comfort, safety or productivity. This can be achieved using personal digital assistants, mobile phones or other portable wireless devices, but these all have limitations, particularly with regard to screen size. The primary solution suggested for implementing KanBIM interfaces is to use large format all-weather touch-screen monitors which do not impose physical restrictions on workers, enable discussion among crews who can all view the same model or animation together, and provide the essential function of easy-to-operate online feedback. This format also enables easy navigation and data access.

Table 1: Task actions and symbols

Action	Description	Symbol
Start Task	Ready to start. Only displayed for a fully mature task scheduled to start on the same day.	
None (task awaits rescheduling)	Not ready to start. Task scheduled to start today, but the maturity level is not yet 100% (indicated by the right hand symbol)	
Update, Stop or Complete task	Task in progress, with number of days remaining until planned completion	
Restart task	Task stopped, with a partial completion quantity indicator	
None	Task completed	
Start Task	Contingency task	
Update	Future task according to weekly work plan, with the remaining duration until the planned start	

Achieving stable workflow is the basic method for minimizing waste of labor time in construction. Stability is not only important directly, it is also the basis for methodical process experimentation ('management by testing of hypotheses'), which is a key tenet of the Toyota Production System (Liker 2003). In the LPS[®], the 'percent plan complete' measure is used to help project organizations learn about the reliability of their plans and thus improve plan stability, but it is a retrospective measure. The KanBIM system deals with plan stability on two levels: the planning process and the execution. In planning, it uses the maturity index as the main parameter for deciding which work package or task

will be done during the week. Every task has its maturity index computed as soon as it is created, based on the work package maturity, task type and the objects it represents. As the maturity index is time dependent, the system will show the highest value that will be achieved during the following planning week together with the earliest day on which this value will be realized (see Figure 4).

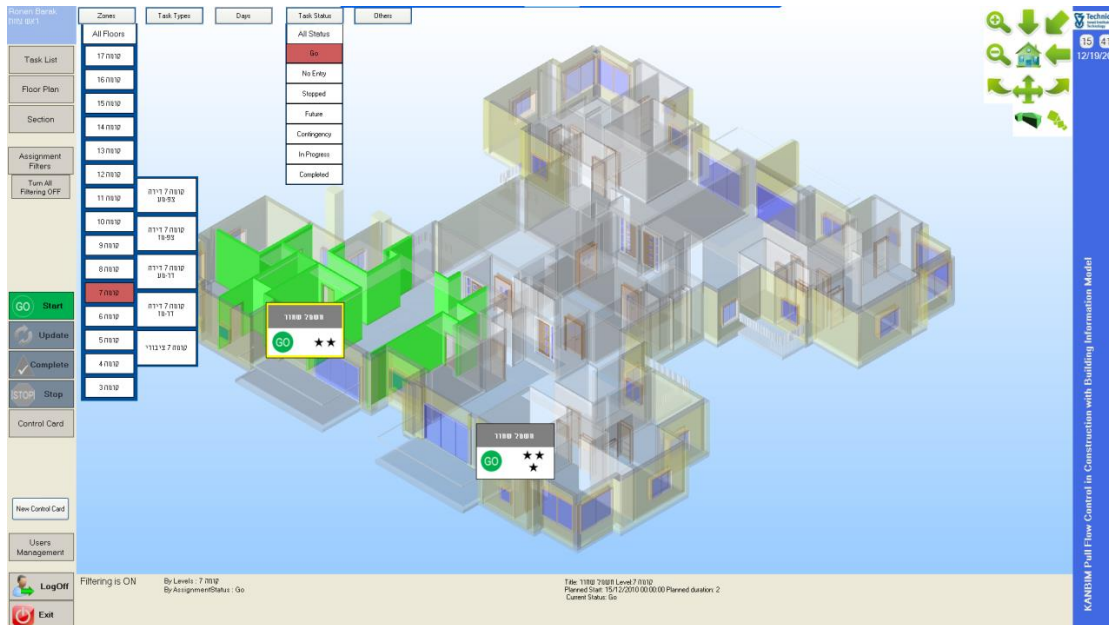


Figure 5: Selection of a task and highlighting of its building elements

During execution, the KanBIM system works to maintain plan stability by applying the principle of ‘sticking to plan’ while at the same time enabling rapid negotiation and thorough coordination of any necessary changes to the plan. A crew leader cannot start a task that is not scheduled for the particular day, even if it is mature. This basic rule derives from the complexity of construction projects and the notion that a crew leader might not be aware of the consequences of the new start day on the rest of the plan. The pitfalls of potential negative impacts on other trades and the danger of ‘making-do’ (Koskela 2004) and subsequent rework mean that plan changes must be negotiated and recorded. The system enables negotiation by facilitating ad-hoc toolbox meetings within a crew with real-time information, or conversations between all those who might be influenced from rescheduling the task so that the new plan will not compromise their work.

Specifically denoted ‘contingency tasks’ are another means to maintain plan stability. A contingency task is a stand-alone task, with no external constraints to other trades, which each crew can carry out without interfering with the overall plan. Whenever the plan is changed and a crew is idle, it should select from its mature contingency tasks that task whose PFI is highest, so that even when the plan cannot be followed, the level of work in progress is not allowed to increase.

The linguistic action theory (Macomber and Howell 2003) suggests that the work is conducted as a conversation built on five actions: declaration, request, promise, assessment and assertion. These five language actions are implemented in the KanBIM

system, starting with the declaration of work when the planning team collectively approves the weekly work plan. The request for action is presented in the form of a 'GO' symbol which appears on all tasks that are scheduled and ready. When a crew leader presses the 'START' button, he or she is explicitly committing to the task content and making a promise to finish it as scheduled. During execution, the default assessment is that the work progresses as planned. However, if a crew leader encounters a problem the UPDATE function can be used to a) "call for help" by identifying the problem and alerting all concerned and b) to reschedule completion if the interference cannot be resolved by the original date. The UPDATE button serves as an ANDON signal, in much the same way as the amber traffic light button was used to call for help in an earlier non-computerized lean construction application (Pereira 1998). In a more severe situation the user can use the STOP button for declaring task halt. When the task is complete, final assertion is made by using the COMPLETE button, which also generates a pull signal for inspection of the work.

The principle 'Implement pull flow control' has a particular meaning in the KanBIM context. A major problem in construction projects is that subcontracted work crews, when allowed to pursue their own priorities, tend to prefer to open as much work space as possible to build up a buffer of work in progress inventory (WIP) that shields their productivity from that the instability of upstream crews. In a lean construction system, preference should be given to completing products (rooms, apartments, spaces etc.) in order to reduce WIP and cycle times. Although it is not possible to achieve a true pull flow regime in most construction projects, because construction does not have steady state production systems with continuous flows of similar products, it is nevertheless possible to apply a conscious strategy to give priority to work in spaces whose subsequent work packages are mature, ideally all the way through to their completion. This state of readiness of the sequence of downstream tasks is reflected in the pull flow index. Evaluating the index and communicating it to work crews is intended to pull crews to prioritize spaces that can be completed and thereby removed from WIP. Such strategies have been proposed and evaluated using simulation by Brodetskaia, Sacks et al. (2011).

Field Tests

The field tests consisted of three independent periods of observation, each including a Thursday site planning meeting and data collection through the entire subsequent working week. Observations were made of execution of the finishing works in the second tower of a large residential construction project, which had four 22 story towers with a total of 320 apartments, a basement with two large parking floors and a community center building. Throughout each period, a researcher walked through the building, from the top to the bottom, recording the activity of all the crews. Each cycle took approximately 30 minutes. Productive value-adding activity, support activity and non-value-adding activity were recorded for each worker, as was the number of workers present for each crew and the start, stop or completion times of each task.

The first period of observation gathered data on the existing work patterns to provide a basis against which the impact of the KanBIM™ system could be compared. This period also served to familiarize the crews with the observer and to refine the data recording technique.



The second period took place one month later. In this period, the KanBIM™ workstation was provided in the building using a 42" touch screen mounted on a trolley. The focus in this period was to evaluate the works superintendent's use of the system, to familiarize the workers and crew leaders with its interfaces and operation, and to identify any bugs or other problems that might hamper the third and final round of observations. Researchers were on hand to help the superintendent and crew leaders with its operation. The results of this period provided valuable input regarding necessary improvements to the system as a whole, preparing if for the third and final period.

The goal of the third period was to observe the system in use and to allow measurement of key performance indicators of plan stability and of productivity. It took place five weeks after the second period, to allow time for enhancement of the prototype. In the third period, access was also provided using a wide screen laptop computer working on the same database. This setup was possible because data concurrency issues were automatically handled by SQL Server. Due to the lack of proficiency at the site with preparation of a detailed and mutually agreed weekly work schedule, the third period was preceded by a Last Planner® meeting facilitated by the research team.

Experimental Measures

A number of measures were used to reflect the performance of the project in each period of observation. They include the standard LPS® measure of percent plan complete (PPC) and measurements of value-adding, supporting and non-value adding work times. The first measures the degree to which planning is effective and reliable (Ballard 2000). The latter three are common in work studies that aim to identify forms of waste in production (for thorough definitions and discussion of their use in construction, see Diekmann et al. (2004), Oglesby et al. (1989) or Forbes and Ahmed (2011)). However, these proved to be inadequate in certain respects, and so two additional measures were added.

Due to the proximity of alternative work in the other towers on the same site, trade managers tended to shift workers between buildings, and even to other sites, whenever work could not be pursued productively. Thus it was observed that time spent waiting for work that proved to be immature was kept to a minimum, and the effect of improvident planning that would otherwise have been measured as non-value adding time was not reflected in the observed data. To reflect these absences, a measure called the 'Lost Work Potential' (LWP) was defined. It is computed as the difference between the total planned hours and the actual hours (of all three types, value-adding, supporting and non-value adding) observed.

The 'Labor Stability Index' (LSI) was defined to reflect the degree of stability of the labor supply under such conditions. This measure is defined as the ratio of the total number of mobilizations/demobilizations of workers for each team during performance of its tasks through a given planning period, to the total number of work days supplied. For example, a team of five workers who released two workers at the end of the first day and mobilized them again at the start of the third day of a four day task would have an LSI of $4/18 = 0.202$.

Results

Observation Period #1: Control

In the initial observation period, before introduction of the system, production on site was observed to be emergent rather than planned. The site management team and the subcontractor crews had no previous exposure to lean construction, but the general contractor did have traditional weekly planning procedures in place. The make ready process was effective in the mid-term, but in the short-term it failed to manage completion and quality assurance of pre-requisite tasks. Lacking the ability to form a clear mental picture of the current status of the work underway and without knowledge of the maturity of future tasks, team leaders spent time gathering information and made ad hoc decisions about allocation of workers to tasks. The resulting PPC was just 33%, and the average LSI was 1.16 (see Table 2). Value-adding and support hours totaled a little less than 50%.

Table 2: Results for Observation Period #1 (Control)

Crew	Flooring	HVAC	Waterproofing	Drywalls	Total
Crew size	3	2	2	7	14
Planned hours	90	60	50	221	421
Value adding hours	52.4	18.2	31	99	202
Support hours	2.3	0.8	2.5	2.5	7.9
Non-value adding hours	12.8	1	10	4.5	28.3
Lost work potential hours	22.5	40	6.5	115	184
Mobilizations/demobilizations	8	15	6	8	37
Labour Stability Index (LSI)	0.41	1.2	2.9	1.1	1.16

Observation Period #2: Familiarization

The second period of observations aimed to familiarize the site personnel with the system and to provide the opportunity for improvements prior to the experiment conducted in the third period. The most important results concerned the usability of the system and the utility of the information it provided.

In preparation for the week, the researchers compiled the weekly work plan together with the superintendent and entered it directly into the KanBIM™ database. The monitor was placed in the building where it was easily accessible to all, but only the superintendent was asked to update the system with reports of the start, stop and completion of tasks. By the third day, the superintendent was able to clearly formulate potential benefits for his own work. Among them, he cited: greatly reduced time spent gathering information about the status of the work, the locations of crews and deliveries of materials; ability to guide crews to work that is needed; recording and follow-up of issues that require his attention; and direct access for all to updated design information. He also noted that the system was dependent on accurate reporting directly in the system by the crew leaders themselves. He requested a number of improvements, including display in context of contact information for all crew leaders, daily summary reports of project status and problems, and provision of the system on a personal device.

The crew leaders, who observed the system throughout the week, were also asked to comment. They emphasized that their primary driver was to achieve high productivity for all the labor they committed to the project on any given day. They provided numerous examples of inefficient work where time spent waiting for information and decisions on unresolved issues prevented them achieving their full potential. Therefore, access to comprehensive information about the status of the work, and in particular the maturity of the tasks planned for their teams, would allow them to better plan their resource allocations. Access online outside of regular working hours was an important requirement.

The work patterns were recorded during this period in the same way as during the first period. The PPC was 47% and the average LSI was 1.03. Value adding and support hours totaled 63% of hours planned. Although these figures reflect better performance than in the same period, they cannot be assumed to reflect any influence of the use of the prototype system. At best, they may reflect the researchers' assistance provided in preparing the weekly work plan and in initiating discussions between the superintendent and crew leaders around the monitor.

Table 3: Results for Observation Period #2 (Familiarization)

Crew	Electrical	Plumbing	Flooring	Sprinklers	Plaster	Total
Crew size	5	4	3	5	1	18
Planned hours	125	100	70.5	125	25	445.5
Value adding hours	70.5	18	54.4	102	8.7	253.6
Support hours	4.3	12	2.3	7.5	0.8	26.9
Non-value adding hours	37.5	3	0	0	0	40.5
Lost work potential hours	12.7	67	13.8	15.5	15.5	124.5
Mobilizations/ demobilizations	11	12	3	4	6	36
Labour Stability Index (LSI)	0.91	2.65	0.5	2.97	0.54	1.03

Observation Period #3: KanBIM™ Operation

The third period of observations was intended to test the ability of crew leaders to use the system interfaces and to better assess the utility it brought to the superintendent. As an early prototype functioning in experimental conditions, the implementation was limited in a number of ways:

- A single week is too short a time to achieve full integration with all the subcontractors, and the commercial terms requiring its use for reporting cannot be introduced.
- The maturity index could not be computed as not all inputs were available (such as links to the company's procurement system for material delivery status or equipment planning).
- The planning module had not been implemented, so that weekly work planning had to be performed offline and changes to the plan could not be negotiated as envisaged in the KanBIM™ requirements outline.
- The system was only accessible through a single large format touch screen and one laptop - interfaces for personal tools were unavailable.

An additional limitation was that the project had not used the LPS[®], so that it is difficult to distinguish the impacts of better planning from those of the system per se. Nevertheless, the experiment was effective in terms of the objectives defined for it: i.e. to assess the utility to the superintendent and the ease of operation for the crew leaders.

The experiment began with a Last Planner[®] style weekly work planning meeting at which all the participating crew leaders were present. In the absence of a working prototype for the system's work planning and negotiation module, the meeting was held using posters with tables representing the locations and the days of the week. Crew leaders used colored notes to assign their crews, creating a visual platform for negotiation with the other crews. The notes required them to state the number of workers assigned to the task and to explicitly check fulfillment of a list of task-specific pre-conditions with respect to their expected maturity. The complete weekly work plan was then entered directly into the database.

Testing of the KanBIM[™] system was a success in that all the crew leaders (with the single exception of the electrical crew leader) were engaged, used the interface with ease, and reported their progress throughout the subsequent week. No problems were encountered with use of the system, and the log of reports made showed only minor discrepancies with the live observations of start, stop and completion of tasks. The superintendent's role proved to be central: he repeatedly encouraged crew leaders to report reliably, and used the system to ascertain the status of the project three to four times each day. Contingency tasks (tasks that are mature but not scheduled for a specific day because they are intended to provide work when scheduled tasks cannot be started or completed) were identified using the system and executed. Crew leaders did not use the system to retrieve design information from the building model itself, but they did access the 2D marked up client change drawings.

The results of the work study observations are listed in Table 4. The PPC rose to 62% and the average LSI was reduced to 0.9. Value adding and support hours totaled 48% of hours planned. Although the PPC rose when compared with period #2, the labor utilization rate was lower. This is partly due to the fact that far more labor was assigned during period #3 (31 vs. 18 workers), which meant that while plan failures were fewer in number, their consequences were more severe.

Table 4: Results for Observation Period #3 (Experiment)

Crew	Plastering	Drywall	Flooring	Windows	Electrical	Sprinklers	Total
Crew size	7	6	5	3	4	6	31
Planned hours	322	291	193	293	195	190	1,483
Value adding hours	198	111	84	19	47	37	496
Support hours	51	45	36	26	10	47	214
Non-value adding hours	41	43	10	21	18	28	161
Lost work potential hours	33	93	64	227	119	78	613
Mobilizations/demobilizations	18	23	14	10	9	8	82
Labour Stability Index (LSI)	0.59	1.1	1.05	1.53	1.15	0.64	0.9

Summary

Under the initial workflow conditions observed on site, the trade crews made little or no effort to work according to management's plans. Each trade determined its crews' progress through the building in one of three ways:

- Crews with tasks that were independent of client design changes, such as plastering and sprinklers, simply progressed from floor to floor up the building according to plan.
- Crews who were dependent on design information, such as floor tiling, maintained stable crew size but progressed ad hoc through the building according to task maturity, which largely depended on delivery of information.
- Crews who had multiple pre-requisite dependencies, such as plumbers and drywall installers, progressed as mature work emerged, with large fluctuations in crew size. These crews made little or no effort to work according to management's plans, performing tasks that became ready day to day rather than adhering to the plan.

With the prototype system in place, and with the benefit of a negotiated and filtered weekly work plan, some improvement was achieved. PPC rose and the LSI declined, both indicating a more stable production system. Nevertheless, the numerical results reflect short term impacts and cannot be considered reliable indicators of fundamental change. Rather, the main achievement of the experimentation at this stage is in the acceptance of the system by the trade crews and in demonstration of the facility of its use.

Conclusions

The KanBIM™ system is the first of its kind, in that no IT application has previously been proposed for workflow control on site that brings together both the process information and the product information in an integrated way, with a 'live' BIM interface and embedded support for lean construction workflows.

The observations pointed to positive potential effects of the system on the ability of site personnel to visualize the process itself, with a reduction of wasted time spent



'looking' for work. The site superintendent summarized his views with the claim that the system would enable him to 'essentially double the scope of work that he could reasonably supervise'.

A number of potential problems and drawbacks were also identified. Like many IT systems, the reliability and completeness of the data in the system is a key determinant of how useful it will be. Task content and information should be detailed at a more fine grained level of detail than was done for the experiment. Tasks with a procedural gap, such as curing of concrete, must be split so that completion of the different stages can be reported. Design changes and other product information must be continuously updated in the building model in order for it to be a useful resource.

Additional recommendations were made for improvement of the system. Among them: preparation of a daily report of all the incomplete make-ready actions that are still needed, with a measure of their urgency in terms of bringing tasks to maturity; automated alerting of tasks that are 'frozen' (discontinued at the start of work on any day due to absent crews); automatic pull of an inspection by the superintendent or site engineer when a task is reported complete, and linkage between reporting, checking and progress payments; provision of online access to crew leaders at all times, not only on site; provision of the system on personal tablet computers and other mobile devices.

Further research is needed in order to test the facility of planning with the KanBIM™ system, which requires online access to material, equipment and other management information systems. As with any IT solution applied to planning, accurate and up-to-date information from all of the supply chains is essential for generating the situational awareness that the system is intended to provide its users. More fundamentally, only once a more comprehensive prototype is developed will it become possible to begin to test what depth of lean education of trade crew leaders and sustained support for site managers is necessary in order to make the information system effective.

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Sacks, Barak, Belaciano, Gurevich & Pikas: KanBIM Workflow Management System: Prototype implementation and field testing

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