FIELD TESTS OF THE KANBIM™ LEAN PRODUCTION MANAGEMENT SYSTEM

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ABSTRACT

The KanBIM™ system is designed to support lean work flow control on construction sites. It facilitates short-term work planning and monitoring, providing clear visualization of the maturity of tasks planned and the status of work under way. The goal of the KanBIM research is to determine whether a BIM based workflow information system can help construction personnel implement lean pull flow strategies. An early prototype of system, with field reporting interfaces, a central database and a building information model, was implemented and tested on a large residential construction site. Although PPC and other results were measured, the main significance of the results lie in the site personnel's positive experience with the system and their observations of the ways in which it could influence the behaviour and productivity of crews. These included recognition of the strong impact the system had in encouraging well-informed discussion and negotiation between crews concerning coordination of their work. The participants identified specific benefits a full implementation could bring to subcontractor trade managers, superintendents and various project management functions.

KEY WORDS

Information systems, Building information modelling, Lean production control, Process visualization, Field trials.

INTRODUCTION

The KanBIM™ System is a management information system comprising procedures, software and hardware designed to support lean work flow control on construction sites. It facilitates short-term work planning and monitoring, providing clear visualization of the maturity 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), which are the primary influences on its development. '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 et al. 2003). BIM refers to the process of compiling parametric object-oriented 3D computer models of buildings and to the variuos technologies used to compile and exploit them (Eastman et al. 2011).

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The motivation for development of the system is three-fold:

a) To facilitate the deep procedural and organizational changes that are required for effective long-term implementation of the Last Planner System® (Ballard 2000). There is a growing recognition on the part of many practitioners and researchers that despite the clear benefits of the Last Planner System® (LPS), 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. 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 et al. 2009).
b) Analysis of the synergies between lean construction and BIM has revealed that there are a number of areas in which the high quality of **product** information provided by information modelling 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 (Sacks et al. 2010a).
c) Earlier research provided 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 et al. 2009). Visualizations of flow and of production status, such as ANDON signals, have been used to good effect in lean implementations (Liker 2003).

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

- 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

The goals of the research described below were to make an initial assessment of the ways in which a BIM based workflow information system can help construction personnel implement lean pull flow strategies, and to collect assessments of existing and missing functionality from potential users. This was accomplished by implementing a working prototype that could fulfil some of the functions at the workface (with special emphasis on the ability to visually communicate the status of the production process and to improve work flow and plan stability) and by running field tests using the prototype.

METHODOLOGY

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, as shown in Figure 1. 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. 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.

KANBIM™ PROTOTYPE DEVELOPMENT

The KanBIM™ prototype software used for the field experiments was implemented in the Microsoft .NET Version 4.0 environment using the C# language in Microsoft Visual Studio, Autodesk Navisworks® COM viewer window and Microsoft SQL Server 2010. It has three main components: the user interface, the model viewer and the database.

The user interface is used for all interactions with both the process data and the 3D model. That includes filtering through assignments, selecting and zooming to assignments as well as reporting starting, stopping and completing assignments. 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 site.

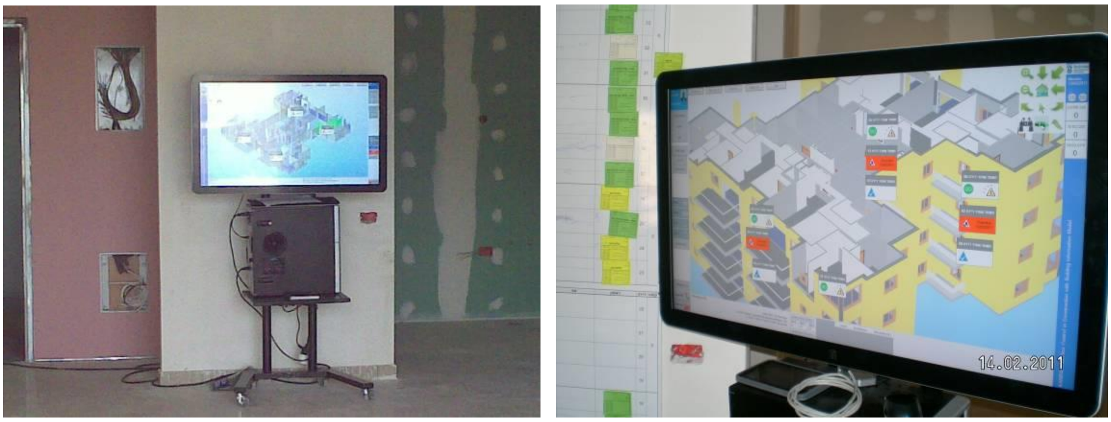

Figure 1: Deployment of the KanBIM™ system on site for the second and third observation periods.

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 ‘assignment labels’ or controls, which represent all of a team leader’s assignments that are scheduled to start in the current weekly work plan, assignments that are in progress, recently completed assignments, and any assignments that had to be stopped prematurely. A number of examples of assignment labels are shown in Figure 2. Each assignment also has a control card that can be opened to display information about the assignment’s precedents: the space where the work is to be done, the assignments which must be completed before the current assignment can start, the location and availability of materials and equipment, information about design changes, and updated drawings.

A user can perform three actions on assignments to update their status, as summarized in the flowchart shown in Figure 3. In order to start an assignment, the user would select the assignment, click on the start button, and then expressly confirm his/her commitment to completing the task as planned. Once the assignment is committed to, its status would change to ‘work-in-progress’. If a problem should occur that prevents a crew leader from completing a task, the stoppage should be reported by selecting the assignment and clicking the Stop button. The dialog shown in Figure 4 is presented, where the user can define what the reasons for the stoppage are. The final action for an assignment is to report completing it.

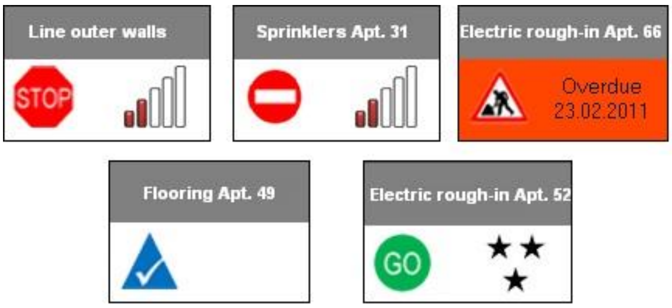

Figure 2: Examples of assignment labels

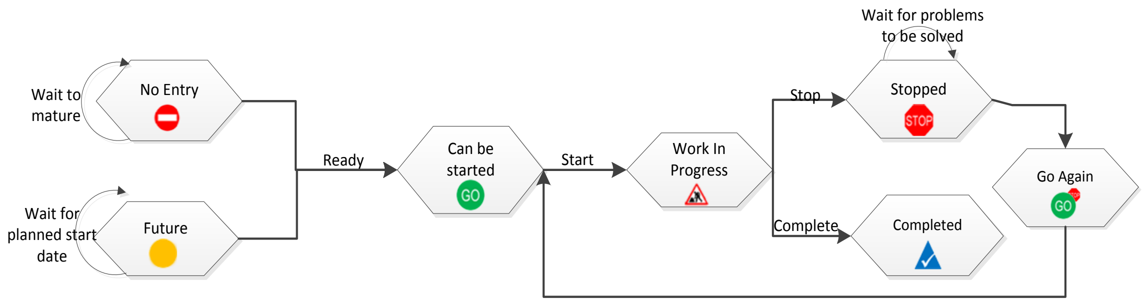

Figure 3: KanBIM™ status cycle

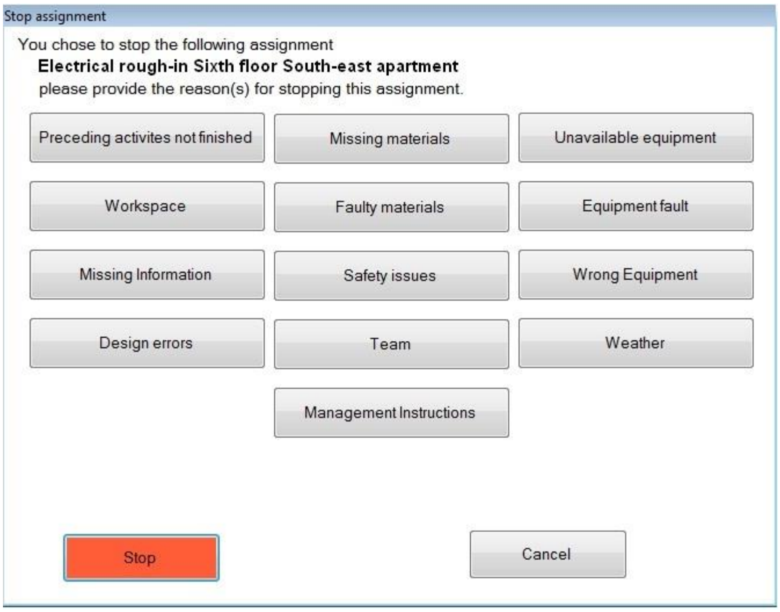

Figure 4: KanBIM™'s "Stop an assignment" dialog box

The data describing assignments, crews, workers and contractors is all stored in the SQL Server database. Every assignment has model elements, such as walls, floors, columns, partitions, etc., related to it. The model elements are stored in the 3D model. When an assignment is selected, its related model elements are highlighted in the model (Figure 5). Every assignment also has a space, which indicates a work zone (this can be a single apartment, a lobby or a number of apartments).

EXPERIMENTAL SETUP

The first step in setting up the system for experiments was to model the building using a BIM tool. This was done in Autodesk REVIT®, which provides one of the many file formats supported by the Navisworks model viewer incorporated in the KanBIM™ prototype.

The second step was to associate planned tasks with the building model objects. Thirdly, the project manager, the works superintendent and the crew leaders were enrolled as users with their respective photos and contact data.

Figure 5: Selection of an assignment and highlighting of its building elements

EXPERIMENTAL MEASURES

A number of measures were used to reflect the performance of the project in each period of observation. They include the standard Last Planner System™ measure of percent plan complete (PPC) and lean process measures of value-adding, supporting and non-value adding work times[4]. 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' was defined. It is computed as the difference between the total planned hours and the actual hours (of all three types) 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 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.

[4] For definitions of these, please see CII report Diekmann, J. E., Krewedl, M., Balonick, J., Stewart, T., and Won, S. (2004). "Application of Lean Manufacturing Principles to Construction." The University of Colorado at Boulder, Boulder, CO.

FIELD TESTS AND 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 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 details in Table 1). Value-adding and support hours totalled a little less than 50%.

Table 1: 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, but his main observation was that all were dependent on accurate reporting directly in the system by the crew leaders themselves. The potential benefits he cited included 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 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. Their main comment was 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 in formation 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. Thus access online during the evening or on weekends was an important requirement.

The work patterns were recorded during this period in the same way as during the first period (see Table 2). 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 2: 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, as can be seen in Figure 6. 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 3. The PPC rose to 62% and the average LSI was reduced to 0.9. Value adding and support hours totaled 48% of hours planned.

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.

Figure 6: Weekly work planning meeting in preparation for observation period #3.

Table 3: 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

With the prototype system in place, and with the benefit of a negotiated and filtered weekly work plan, some improvement was achieved. As can be seen in Table 4, 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.

Table 4: Summary of Results for Observation Periods

Measure	#1 Control	#2 Familiarization	#3 Experiment
Percent Plan Complete (PPC)	33%	47%	62%
Labour Stability Index (LSI)	1.16	1.03	0.9
Value-adding and supporting work hours/ total planned hours	50%	63%	48%

CONCLUSIONS

The observations pointed to positive potential effects of the KanBIM™ 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 brining 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. More fundamentally, only once a more comprehensive prototype is developed will it become possible to begin to test whether pull flow control can be implemented effectively without thorough lean education of trade crew leaders and sustained support for site managers.

ACKNOWLEDGEMENTS

The authors are indebted to the many individuals at the Carasso Project and the management of Tidhar Construction Ltd. for their involvement and contribution to this research. We particularly thank Mr. Viktor Alhazov, the superintendent for building #2, for his active support in thoroughly testing the system with his subcontractor crews. This research was partially funded by the Israel Ministry of Construction and Housing under grant #2013-011.

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