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EXPLORATION OF A LEAN-BIM PLANNING FRAMEWORK: A LAST PLANNER SYSTEM AND BIM-BASED CASE STUDY

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ABSTRACT

Current Lean Construction and Building Information Modelling (BIM) research has been focused largely on the theoretical aspects related to their integration and synergies. But little attention has been paid to the development of BIM-Lean practical methods to manage projects and provide evidence of the opportunities for performance enhancement. In this paper, we attempt to bridge this gap by proposing a Lean-BIM planning framework by integrating the Last Planner System and BIM.

The development of the proof of concept of the BIM-Lean planning framework was undertaken by comparing two case studies: one using only LPS and the other using LPS and BIM. We followed construction activities related to rough work in two comparable building projects as part of the field office staff. We gathered project data and analysed and compared planning procedures in both projects. Data collected included: weekly and lookahead planning meetings analyses; design requests for information (RFI); and LPS metrics. We then used flowcharts to document both planning processes and the improved planning proposal, and also, integrated the different planning levels. Results show that the coordinated use of LPS and BIM generates an increase in PPC, a decrease in reasons for non-compliance, a shortening of the meeting durations, and a decrease in the total number of design RFIs. The improved planning proposal combines LPS+BIM and facilitates the interaction of a larger and diverse number of project stakeholders around BIM manipulation in planning meetings. Project meetings become more effective and the communication of project planning improves as a result.

KEYWORDS

lean-BIM, last planner system, RFI

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INTRODUCTION

Information technologies, such as BIM (Building Information Modeling) (Eastman et al., 2008) help stakeholders to better deliver construction projects. For instance, 4D modeling (animation of the construction process achieved by combining the project´s 3D geometry with the planned construction sequence) help the project participants to better understand and communicate the construction plan (McKinney and Fischer, 1998; Kuo et al., 2011). BIM models display design and construction information and hence, help to improve the interaction and collaboration among the project participants (Koo and Fischer, 2000).

The "Last Planner System" (LPS™) is a production control system based on Lean Production. The LPS's goal is to increase performance as a result of improved reliability of planning and reduced variability of workflow. LPS™ acts over four project planning levels. The Master plan produces the initial project budget and schedule, and provides a coordinating map that 'pushes' completions and deliveries onto the project. The Phase schedule produces more detailed and manageable plans from master plans with high complexity level. The Lookahead plan focuses on controlling the flow of work through the production system, detailing and adjusting budgets and schedules 'pulling' resources into play. Commitment planning (short-term period) determines the activities and scheduled work that will be done onsite (operational level) according to the status of resources and prerequisites (Ballard and Howell, 2003; Ballard, 2000).

The ability of a crew to reliably perform work depends on the stability of the workflow. A stable workflow depends on construction preconditions such as resources and prerequisites that should be available whenever they are needed (Koskela, 2000).

LPS™ uses the percentage of plan completed (PPC) as a planning reliability index. The analysis of reasons for non-compliance (RNC) is performed to understand why planned work was not completed. The goal of this analysis is to discover the root causes and rectify the problem. This data provides a basis for improving PPC (Ballard, 2000).

Literature provides some stepping stones for the integration between LPS and BIM. Recent work has proven that the LPS™ can be used in combination with 4D models (a BIM-Lean approach) to improve the understanding of the project progress, and to prepare and provide more useful handouts to the planning meetings' participants (Mora et al., 2009; Khanzode, 2010; Sacks et al., 2011; González, 2012; Toledo et al., 2014). Sriprasert & Dawood (2003) proposed a virtual tool to help visualize physical constraints and the project progress. Bhatla and Leite (2012) proposed a theoretical integration framework of BIM and LPS. However, these contributions do not directly address the challenges of implementing such an integrated approach. They rather discuss an alternative that worked or do not provide any evidence proving that their proposal work in practice (e.g. Bhatla and Leite, 2012). The motivation behind this research is to develop a framework to better use BIM models together with LPS, in order to improve the project planning performance. Also, this paper aims to provide robust empirical evidence for the potential use and implementation of a BIM/LPS framework.

To do so, we compare in this research two similar projects that use LPS for planning. Furthermore, we used BIM in one of them to support the project delivery. We first show the impact of using BIM to assist the use of LPS (Lean-BIM) on the improvement of commonly used lean project performance indexes: percentage of plan completed (PPC), reasons for non-compliance (RNC) and request for information (RFI). We then used flowcharts to document both planning processes and the improved planning proposal. Flowcharts created include master planning, lookahead and weekly schedules, and the way they integrate with each other.

RESEARCH METHOD

We first gather weekly planning data during rough work from both projects. Aspects tracked included planning meetings dynamics –such as meeting durations, participants and their project roles-; LPS indexes –such as percentage of plan completed (PPC) and reasons for non-compliance (RNC)-; and design requests for information (RFI). We analysed the project information and compared the performance of both projects.

We made a diagnosis of existent problems and prepared an improved proposal for project planning using LPS and BIM that were documented using flowcharts for each planning phase (master plan, lookahead and weekly plan).

DESCRIPTION OF CASE STUDIES

We present two comparable case studies in this section. One uses LPS and the other uses LPS and BIM. Following, we show their similarities and differences.

CASE 1: INACAP RANCAGUA PHASE 1

This project consists of two higher education buildings located in Rancagua, Chile. The four floor reinforced concrete buildings consider classrooms, labs, administrative offices, an auditorium, and a library. Total gross area is 11,500 m2 and the rough work phase original duration was 9 months.

Project planning and control was done using LPS and a Master Plan was created at the beginning of the project. There is also a weekly lookahead planning meeting to review the Master Plan activities and plan the work for the next 4 weeks (4 week lookahead planning). In this meeting all restrictions, the responsible to release them and the deadlines are committed in order to execute the project according to plan. There is also a weekly planning meeting, where the current week activities are scheduled according to the lookahead plan. At this weekly meeting, project compliance is monitored and LPS performance indexes are recorded and shared (PPC and RNC). During the project execution, the General Contractor submits RFIs to the owner´s representative. Most of them are related to missing drawings and drawing details and specs, geometric interferences and project information validation (due to contradictions or lack of clarity). Latency for RFIs varies widely and was also tracked.

We participated in about 35 lookahead and weekly planning meetings. We recorded the date, start and finish time, participants (and their project roles) and we had access to the meeting minutes. During the lookahead meetings we reviewed the lookahead constrains in tabular form and determined the planning reliability for each last planner. Each week we tracked and shared this planning performance index. During the weekly planning meetings every last planner shared their PPC and next week plan, and RNC were recorded. After the meeting, PPC, weekly plans and RNC were shared in tabular form which was included in next week's presentation.

RFIs were received and channeled through a member of the onsite technical office to the owner representative. They were received as they arose. They were formalized in a paper form followed by an email to the owner representative. We reviewed and classified them, and focused our attention on the most common ones that deals with geometric interferences and project information validation.

We developed four flowcharts to formalize the weekly and lookahead planning cycles (2) and one each to document the dynamics within each meeting (2).

CASE 2: INACAP RANCAGUA PHASE 2

This project consists of one higher education building located at the same site of the previous case in Rancagua, Chile. The reinforced concrete building has two floors and one underground level that include teaching workshops, some classrooms, and a cafeteria. Total gross area is 7,500 m2 and the rough work phase original duration was 5 months and 3 weeks.

Besides the project planning described for the first case, in this project the owner provided a BIM model (Autodesk Revit) which was used in the weekly meetings to show the project details and the scheduled and completed activities. Screen captures for each activity were shared on a meeting presentation, where each day's work was shown with different colors. The owner´s architect performs clash detection and documents RFIs with it. Direct manipulation of the BIM model at the meetings is done at the participants request for details. Lookahead planning meetings and RFIs management took place the same way as described before.

We participated in about 22 lookahead and weekly planning meetings during the rough work phase, which were carried out similarly to the first case study. Main differences can be summarized as follow: (i) besides PPC and RNC tracking, for each RNC a corrective measure was suggested; (ii) an analysis of all topics not covered in previous meeting minutes was added and safety, human resources and material warehouse reports were briefly discussed; (iii) during weekly planning meetings a presentation that included BIM screen captures was shared; (iv) RFIs were still managed as they arose, but during the weekly planning meetings their status was checked and some questions were cleared using the BIM model.

As we did with the first case study, we developed flowcharts to document weekly planning cycles (lookahead planning remains the same, so no map is added) and the dynamics within the meeting. The resulting process maps highlight the changes between both case studies.

RESULTS AND COMPARISON OF CASE STUDIES

We show the main results from the case studies and compared them. Project data for lookahead planning meetings, weekly planning meetings, and RFIs is presented.

LOOKAHEAD PLANNING MEETINGS

For Case 1, project participants spent on average 23.25 men-hours in lookahead planning meetings and the average attendance was 9 professionals representing 5 different project roles. The average duration of the lookahead planning meetings was 2:35 hrs. Planning reliability for all last planners was 66% (measured as % of constrains released as scheduled).

For Case 2, project participants spent on average 19.60 men-hours in lookahead planning meetings and the average attendance was 9 professionals representing 5 different project roles. The average duration of the lookahead planning meetings was slightly shorter than in Case 1 at 2:27 hrs. Planning reliability stood virtually the same at 65%.

WEEKLY PLANNING MEETINGS

For Case 1, projects participants spent on average 18.66 men-hours in weekly planning meetings. 15 professionals representing 5 different project roles regularly took part in the meetings. Others were invited but opted out. The average duration of the weekly planning meetings was 1:52 hrs.

PPC goal for the project was 75.0% and a 76.7% was achieved, with an average variability of 10.1% respect to the average (see Figure 1). Table 1 shows that 89 RNC were recorded for Case 1, with an average of almost 10 RNC/month.

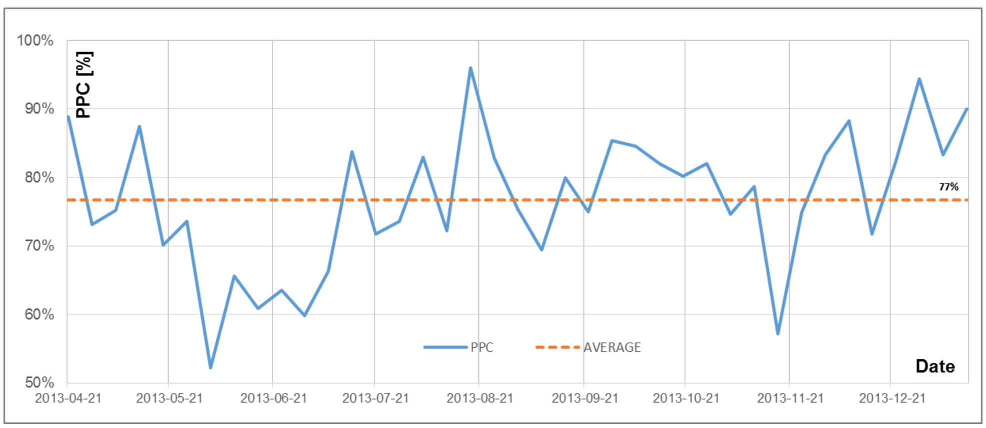

Figure 1: Percentage of Plan Completed - Case 1. Recorded at weekly planning meetings.

Table 1: Reasons for non-compliance - Case 1. Tracked at weekly planning meetings.

Reasons for non-compliance (RNC)	# RNC	Avg # RNC/month
Too many activities assigned to subcontractor	6	0.7
Activity performance overestimation	38	4.2
Wrong planning	35	3.9
Others (planning problems)	10	1.1
TOTAL	**89**	**9.9**

For Case 2, projects participants spent on average 18.54 men-hours in weekly planning meetings. 16 professionals representing 9 different project roles regularly took part in the meetings. The average duration of the weekly planning meetings was 1:30 hrs.

Therefore, at about the same cost (similar men-hours), a larger number of participants and project roles participated in shorter weekly meetings backed by BIM models.

Average PPC was 85.0% (above the goal and significantly better than in Case 1). The average variability was reduced to 4.6% respect to the average (see Figure 2). Table 2 shows that 55 RNC were recorded for Case 2, with an average of 10 RNC/month (no change from Case 1). We can also note from Tables 1 and 2 that most RNC related to planning decreased in Case 2 (performance overestimation or wrong planning).

On top of the performance improvement on LPS indexes and RFI management when we compared Case 1 and 2, we can point out that the use of BIM had a positive impact on last planners during the weekly planning meetings for Case 2. In Case 1, weekly plan was shared in tabular form without much interaction among project participants, while in Case 2, when BIM was used, last planners asked questions and participated in the meeting. The process improvement meant an increase in meeting participation, particularly when defining the work plan and scheduling of concurrent activities (hard to detect in tabular form). The interaction was focalized and even meant a shortening of project meetings from 1:52 to 1:30 hrs. for Case 2. Case 2 learnt lessons reached beyond the project success and were taken by the last planners to their next projects. They requested LPS+BIM integration to their project managers (some of whom were not even familiar with their joint use).

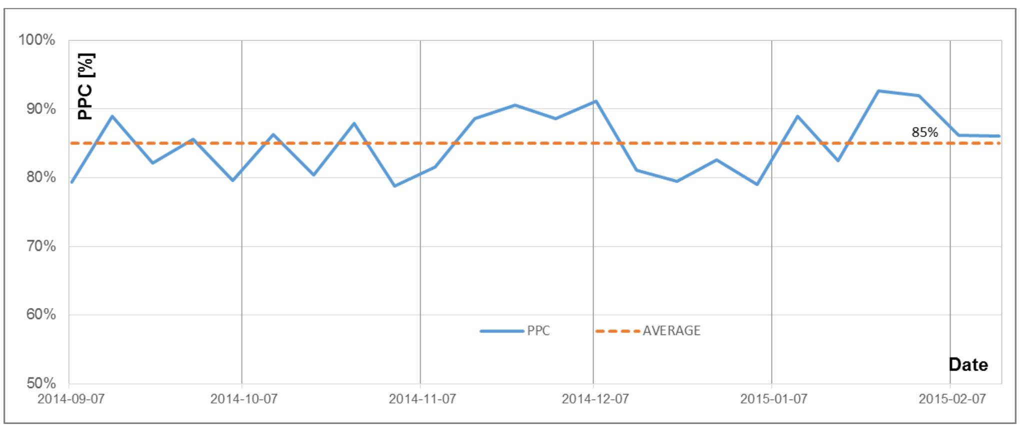

Figure 2: Percentage of Plan Completed - Case 2. Recorded at weekly planning meetings.

Table 2: Reasons for non-compliance - Case 2. Tracked at weekly planning meetings.

Reasons for non-compliance (RNC)	# RNC	Avg # RNC/month
Too many activities assigned to subcontractor	21	3.8
Activity performance overestimation	12	2.2
Wrong planning	17	3.1
Others (planning problems)	5	0.9
TOTAL	**55**	**10.0**

RFIs

For Case 1, a total of 104 RFI were managed during the project rough work. 2.89 RFI/month were issued regarding project geometric interferences, while 2.11 RFI/month were issued about project information validation.

For Case 2, a total of 45 RFI were managed during the project rough work. 1.04 RFI/month were issued regarding project geometric interferences, while 1.04 RFI/month were issued about project information validation. The absolute number of RFI was drastically reduced from 104 to 45 (from 12 to less than 8 RFI/month) in Case 2. Project geometric interferences were reduced from 2.89 to 1.04 RFI/month due to BIM use.

DIAGNOSIS OF PROBLEMS AND LEAN-BIM FRAMEWORK

Though there is a performance enhancement from Case 1 to Case 2, there is still room for improvement. The main problems identified are:

i. BIM model is not shared with all project stakeholders.
ii. There is little sharing and reinforcement of information reviewed and discussed within the lookahead and weekly planning meetings.
iii. Meeting participants came unprepared to lookahead planning meetings which meant long meetings.
iv. RFI related information was not readily available to lookahead planning meeting participants, so a piece of information was missing.
v. There is no explicit connection between lookahead planning meetings and weekly planning meetings.
vi. Though a larger number of participants were invited to the weekly planning meetings, their attendance was not mandatory (and some opted out). However, they could be missing when decision making was necessary for the work plan.
vii. Weekly planning meetings included an agenda with topics unrelated to the weekly work plan development.

Based on the project performance improvements observed from Case 1 to Case 2 and the problems just listed, we identified the following features that our framework should include:

- The final Master Plan and the corresponding 4D model should be shown to the entire project team.
- On site informative bulletin boards have to be available to display all information about lookahead and weekly planning meetings. They should be updated weekly.
- Every participant of the lookahead planning meeting should analyse the lookahead activities before the meeting.
- RFI will be part of the lookahead planning meetings in order to consider design constrains and communicate solutions and commitments to weekly planning meetings. The constrains status should be sent by email to last planners.
- Subcontractors' last planner related to critical activities must take part in weekly planning meetings.
- Safety and human resources reports will not be part of the weekly planning meetings (kept out the agenda) to focus the discussion on the work plan.
- A set of interrelated process maps will facilitate the adoption of the proposed framework.

Figures 3, 4 and 5 explain how the proposed framework works.

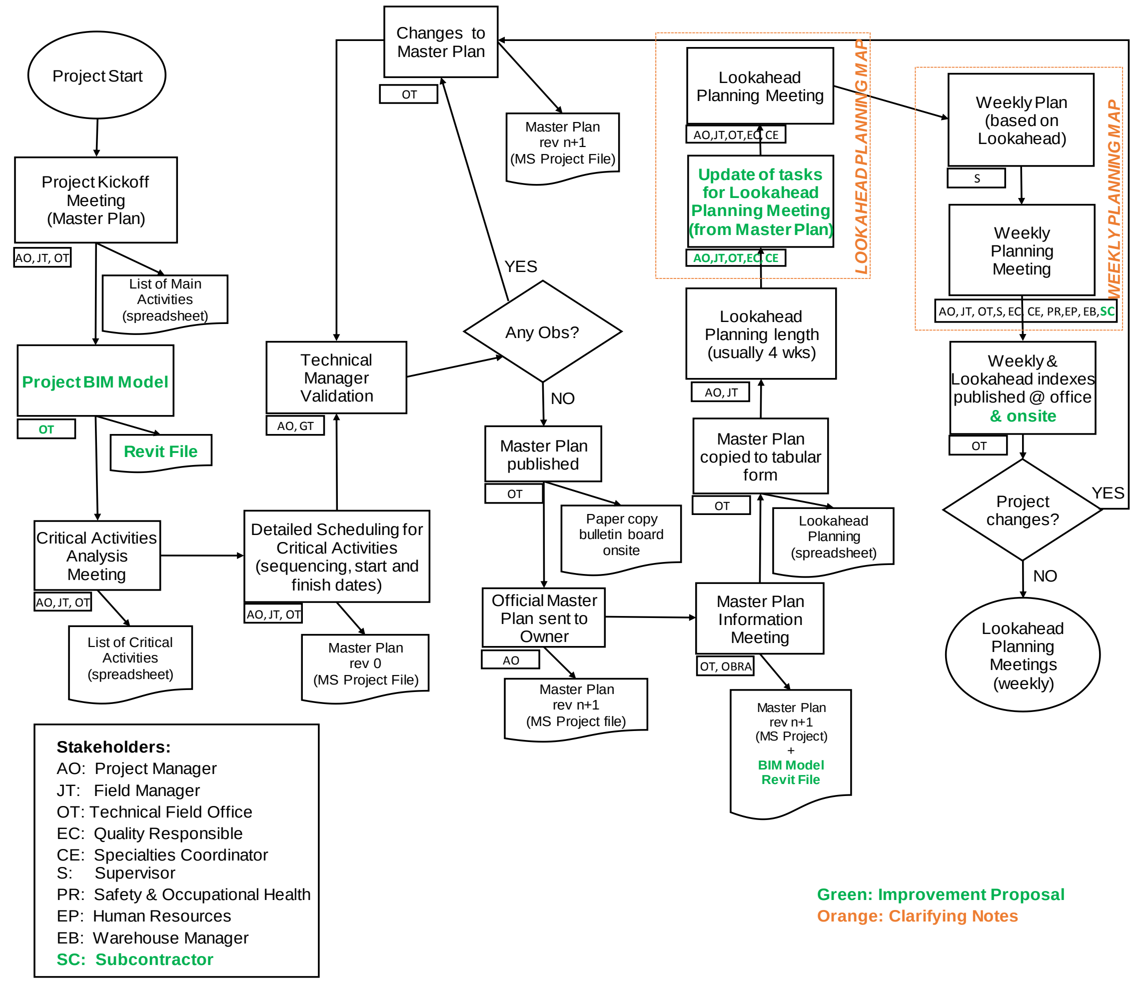

Figure 3: Improved proposal for BIM-LEAN framework.

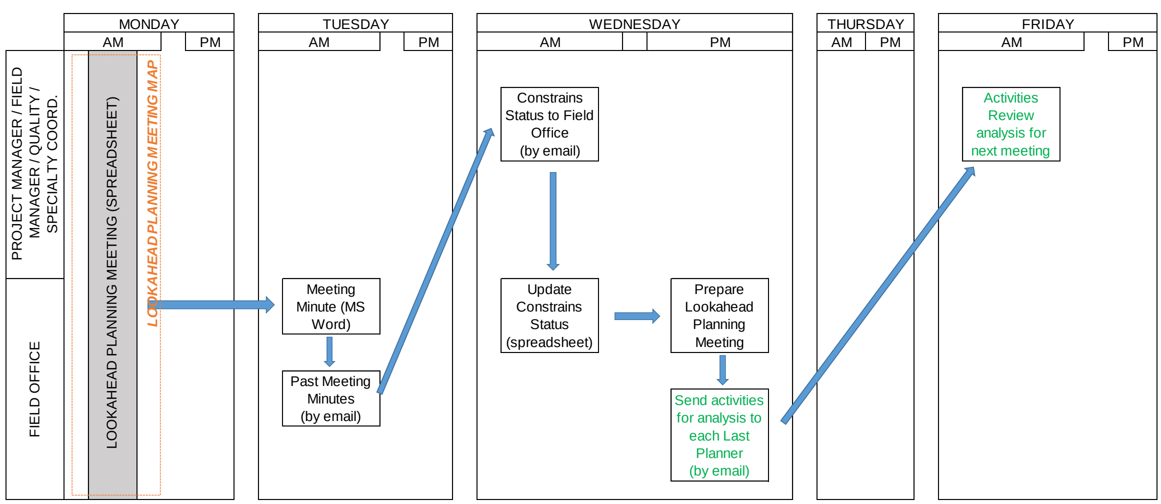

Figure 4: Improved proposal for lookahead planning.

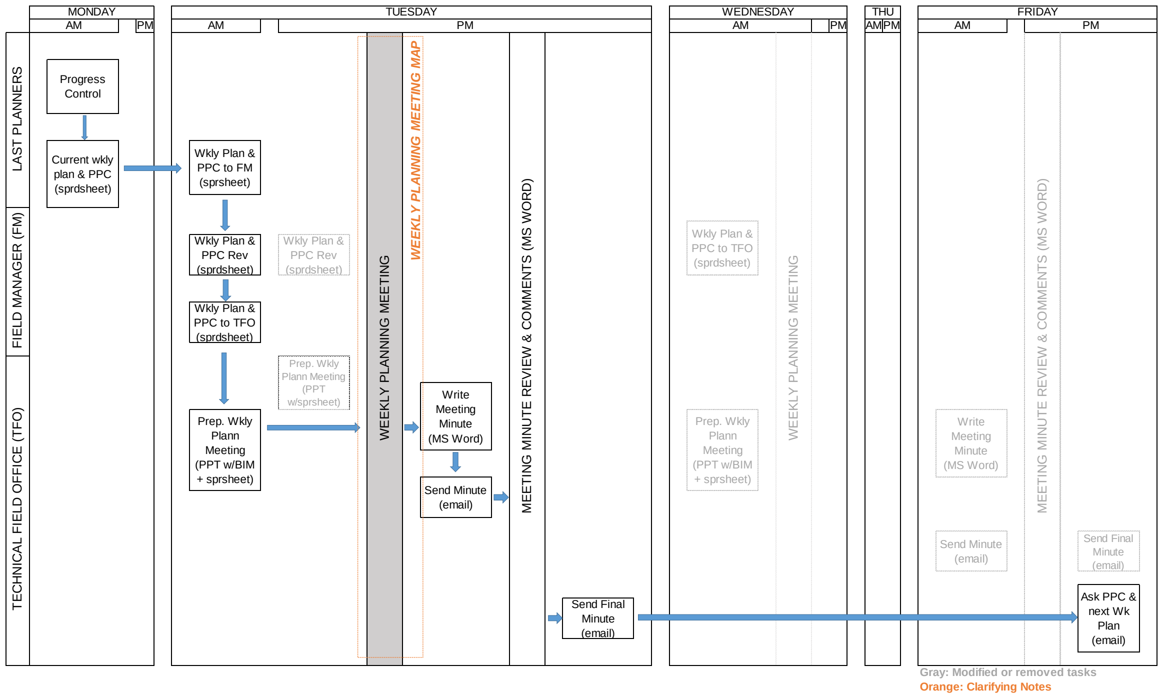

Figure 5: Improved proposal for weekly planning.

CONCLUSIONS

Lookahead planning meetings suffered virtually no changes (in duration and last planners' reliability). We should note that BIM models were not used for lookahead planning.

Regarding weekly planning meetings, LPS+BIM enabled an increase of participants (from 15 to 16), representing a larger number of project roles (from 5 to 9) by reducing the meeting duration from 1:52 to 1:30 hrs. while maintaining the total number of men-hours spent on this type of meeting (a little over 18,5 hrs/week). Therefore, at the same cost (men-hours) a better project understanding is reached when using LPS+BIM.

PPC improved from 76.7% to 85.0% and PPC variability decreased from 10.1% to 4.6% for LPS+BIM. Therefore, planning reliability improved. We can also note that most RNCs related to planning decreased in Case 2 (performance overestimation or wrong planning).

Regarding RFI management, we observed a big improvement when using LPS+BIM. Absolute number of RFI decreased from 104 to 45 (from 12 to less than 8 RFI/month). Project geometric interferences were reduced from 2.89 to 1.04 RFI/month due to BIM use, because they were earlier detected in weekly project meetings and solved with the aid of the BIM models (no need to create a RFI).

Lessons learnt from both cases were incorporated in the Lean-BIM framework described through a set of interrelated flowcharts.

Our findings are grounded on the reinforced concrete building construction case studies presented during the rough work phase. Further work is needed to generalize the results to the finishing phase, and/or other building types. Both projects were executed by the same general constructor and same project team, so a learning curve effect should not be discarded when explaining the performance differences among both case studies.

REFERENCES

Ballard, G. (2000) “The Last Planner System of Production Control.” *Ph. D thesis*, University of Birminghan, Faculty of Engeering, School of Civil Engineergin, UK.

Ballard, G. and Howell, G. (2003). “An Update on Last Planner.” *Proceedings IGLC 11*, Blacksburgh, Virginia, U.S.A, July 16th -17th.

Bhatla, A. and Leite, F. (2012). “Integration Framework of BIM with The Last Planner System.” *Proceedings IGLC 20*, San Diego CA, USA, 18-20 July.

Eastman, C. M., P. Teicholz, R. Sacks, and K. Liston (2008). *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Architects, Engineers, Contractors and Fabricators*. John Wiley and Sons, Hoboken, New Jersey, USA.

González, A. (2012). “A Proposal for Implementing the Last Planner System Supported by 4D Technology at the Building´s Structural Concrete Work Stage.” *Civil Engineering Thesis*, University of Chile, Santiago, Chile.

Khanzode, A. (2010). “An Integrated, Virtual Design and Construction and Lean (IVL) Method for Coordination of MEP.” *CIFE Technical Report #TR187*, Stanford University, California, USA.

Koo, B., and Fischer, M. (2000). “Feasibility Study of 4D CAD in Commercial Construction.” *Journal of Construction Engineering and Management, ASCE*, 126(4):251-260.

Koskela, L. (2000). “An Exploration Towards a Production Theory and its Application to Construction.” *PhD Dissertation*, VTT Building Technology, Helsinki University of Technology, Espoo, Finland, 298 pp.

Kuo, C., Tsai, M., & Kang, S. (2011). “A Framework of information Visualization for Multi-System Construction.” *Automation in Construction*, 20(3), 247-262.

McKinney, K., & Fischer, M. (1998). “Generating, Evaluating and Visualizing Construction Schedules with CAD Tools.” *Automation in Construction*, 7(6), 433-447.

Mora, M., Fuster, S., & Alarcón, L. (2009). “From the site office to the field: Last Planner System with 4D Planning.” *Proceedings V International Conference and XVII National Conference of Civil Engineering Students*, Lima, Perú.

Sacks, R., Barak, R., Belaciano, B., Gurevich, U. & Pikas, E. (2011). “Field Tests of the Kanbim™ Lean Production Management System.” *Proceedings IGLC 19*. Lima, Peru, July 13th-15th.

Sriprasert, E. and Dawood, N. (2003). “Multi-constraint information management and visualisation for collaborative planning and control in construction.” *ITcon* Vol. 8, Special Issue eWork and eBusiness , pg. 341-366, http://www.itcon.org/2003/25.

Toledo, M.; González, V.; Villegas, A.; Mourgues, C. (2014). “Using 4D Models for Tracking Project Progress and Visualizing the Owner’s Constraints in Fast-Track Retail Renovation Projects.” *Proceedings IGLC22*, Oslo, Norway, June 23-27.