USING 4D MODELS FOR TRACKING PROJECT PROGRESS AND VISUALIZING THE OWNER´S CONSTRAINTS IN FAST-TRACK RETAIL RENOVATION PROJECTS

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ABSTRACT

One of the challenges of managing fast-track projects is the high level of uncertainty in both project definition and scheduling. Thus, communicating this project information among stakeholders becomes crucial for its success. One of the key stakeholders is the owner, who needs this information to guide its decision making process. When the owner has incomplete progress information, and the schedule constraints are poorly detected, communicated and managed, project delays are highly likely.

In this research, 4D models and some concepts from the Last Planner System (LPS™) such as lookahead planning and constraints analysis were used in order to propose a "BIM-Lean" planning approach. Thus, the identification and communication of project constraints is enabled within the project team, so they can be adequately managed. This research aimed at improving the stakeholders understanding of the project progress and planning reliability.

The renovation of a shopping center, which remained operating during construction, was used as a case study. This case study allowed the project planning and progress control procedures to be assessed and the proposed planning approach to be tested. The final version of it was validated in a Charrette test conducted with both project professionals and civil engineering students. This Charrette measured the participants' understanding of the project progress and constraints management information with and without the proposed planning approach.

The results showed that the planning approach improved the understanding on project progress and owner's constraints management, which was particularly valued by site professionals and owner representatives.

KEYWORDS

4D, BIM, Last Planner, Project Progress, Constraints, Owner.

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INTRODUCTION

The retail industry is constantly under pressure by their clients in need of additional space for the development of their economic activities. The success of these businesses relies often on a reliable estimate of the date when those spaces become available. Adding complexity to this scenario, the chosen delivery process is often fast-track, due to usually urgent space needs. One of the key stakeholders in this type of project is the owner, who needs this information to guide its decision making process. When the owner has incomplete progress information, and the schedule constraints are poorly detected, communicated and managed, project delays are highly likely.

One of the challenges of managing fast-track projects is the high level of uncertainty in both project definition and scheduling. Thus, the tools and methods used to communicate project related information, for both design and construction, among the project stakeholders ought to be efficient to solve problems tied to those project uncertainties (Hoezen et al., 2006). Information technologies, such as BIM (Building Information Modeling) (Eastman et al., 2008) and VDC (Virtual Design and Construction) (Kunz and Fischer, 2012; Senescu and Haymaker, 2009) help the stakeholders with this endeavor. 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 participant to better understand the construction plan and the current project progress (McKinney and Fischer, 1998; Kuo et al., 2011). It has also proven useful to display design and construction information and hence, improve the interaction and collaboration among the different specialties within a project (Koo y Fischer, 2000).

The “Last Planner System” (LPS™) is a production control system based on Lean Production. The LPS’s aim is to increase performance as a result of improved reliability of planning and reduced uncertainty of construction systems. It has been shown that implementation of the LPS™ creates more reliable flow and higher throughput of the production system, resulting in improved productivity (Ballard, 2000; González et al., 2008).

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, creating phase schedules based on targets and milestones from that plan and helping to maximize value generation in the planning process and for all involved. 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 traditional management approach for work planning defines activities and schedule work that will be done, in terms of what should be done from a master plan, with no real consideration for what a crew is actually able to do. 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). However, workflow variability could negatively affect crews' performance, causing idle time or ineffective work (Tommelein et al., 1999).

The overarching criterion in the LPS™ is that activities should only be committed to if they can be performed (i.e., all construction preconditions must be available), thus, work plans will be based on achievable assignments serving as a commitment to what will actually be done (Ballard, 2000).

LPS™ uses the percentage of plan completed (PPC) as a planning reliability index. PPC is the ratio between actual completed activities and planned activities. The analysis of reasons for non-completion (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 this research. For instance, 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 (González, 2012; Mora et al., 2012). Sriprasert et al. (2003) proposed a virtual tool to help visualize physical constraints and the project progress. Chen et al. (2012) studied and evaluated the color scheme selection for 4D modeling according to its intended use. However, these contributions do not directly address the particularities observed in the renovation of retail fast-track projects. The owner, as any other stakeholder can contribute to improve the project performance and it is in its best interest to do so. Therefore, the motivation behind this research is to understand how to better use 3D and 4D models together with LPS elements in order to improve the project progress control and to timely visualize and manage the owner's constraints (those for which he/she needs to be aware of to remove them).

METHODOLOGY

The renovation of a shopping center, which remained operating during construction, was used as a case study. This case study allowed the project planning and progress control procedures to be assessed and the proposed planning approach to be tested. The final version of it was validated in a Charrette test conducted with both project professionals and civil engineering students. This Charrette measured the participants' understanding of the project progress and constraints management information with and without the proposed planning approach.

The research results are presented as follows. First, we show our proposal for 3D and 4D modeling conventions aimed at providing valuable project progress control information to the owner. Second, we show our proposal for visualizing the owner's constraints, e.g., those that the owner can manage and remove. Such proposal includes a formalization of the considered constraints. Third, we show both the procedure and results from the validation exercise performed with the project professionals and the civil engineering students regarding the progress control information and the visualization of the project constraints. The validation also includes qualitative information such as the importance that both professionals and students assign to the displayed information.

PROJECT DESCRIPTION

The research took place at the construction site of a major renovation project at a crowded shopping center in southern Santiago, Chile. The renovation project involved the construction of a 6,934 m2 home improvement retail store and a parking structure of 22,776 m2 in two levels. Both the store and parking structures were built on top of the existing building that was reinforced to withstand the additional loads. The project budget was over US$13 million and the original schedule considered 9 months for construction.

We approached this research from the owner's perspective, because they could verify over and over again that their renovations were often over budget and completed late. On the field, we had first-hand observation on the coordination issues and miscommunication between the general contractor (GC) and the owner representative. The project planning and progress control was deficient and failed to explain the actual progress status. Constraints that the owner could manage or remove were not tracked adequately. Thus, the completion of assigned work was negatively impacted and the project's due date was delayed.

TRACKING PROJECT PROGRESS

Gonzalez (2012) and Mora et al. (2010) highlight the benefits of visualizing scheduled and completed activities with the aid of 3D and 4D models at the weekly planning meetings. They also indicate that such visual aids help the project and meeting participants to better understand the actual project progress. They elaborated on the type of information that the 3D and 4D models convey regarding the project progress control. They agree that the 3D/4D models need to go beyond distinguishing between early or late completion of activities in order to be an effective scheduling aid for the owner's decision making process. Table 1 summarizes both the color coding convention used for the case study's 4D models and the performance information used to track project progress. The color convention follows the field tested recommendations given by Gonzalez (2012), Mora et al. (2010), and Chen et al. (2012). The final version went through several iterations on the weekly meetings to get feedback from the case study's project team. The performance indexes are borrowed from the LPS™ and we suggest they are used jointly with the 4D model. Both pieces of information (Table 1) are used at the weekly coordination meetings for the case study and they refer to the committed progress for a week of work.

Table 1: Information for 4D model project progress control.

Item	Color	RGB Code		
1) 4D elements status				
a. Scheduled activities – previous week	Green	00	255	00
b. Late activities – previous week	Magenta	255	00	255
c. Early activities – previous week	Blue	00	00	255
d. Finished activities – previous week	Gray	140	140	140
e. Pre-existing elements / completed work	Light gray	192	192	192
2) LPS performance indexes				
a. Percentage of Plan Completed (PPC) GC – previous week				
b. Reasons for Non-Completion (RNC) GC – previous week				

Assigned colors to represent the progress status associated with the scheduled activities are very functional and were chosen following Chen et al. (2012) recommendations. The selected color combination highlights the relevant 4D elements (a product element that is colored at a particular point in time to indicate that an action is taken, i.e., work is done at that element during that period of time) and it figuratively sends the other elements to the background (shades of gray). Vivid colors are chosen to show scheduled, late and early activities. Early activities are colored blue (cool color) to signal tranquility, while late activities are colored magenta (warm color) to signal a warning. Finished activities and existent elements are less relevant for progress control purposes, and therefore they are colored less vividly (shades of gray) to focus attention somewhere else. Figure 1 shows an example of our proposal for 3D/4D modeling recommendation and it provides complementary information regarding the PPC and NCR for the weekly progress control.

VISUALIZING THE OWNER'S CONSTRAINTS

This research takes into consideration all the relevant information for the owner's decision-making process regarding the management of its constraints or those on which it has some influence to accelerate the removal of the constraints. Table 2 summarizes the formalization of the proposed approach to visually manage the constraints that the owner can help remove for this case study: design constraints, operation constraints, and project definition constraints. A description and examples are provided for each case.

As in the case for the weekly work planning, the color palette used for the lookahead 4D models is very functional. Warm colors are chosen to highlight 4D elements that represent constraints and to signal a warning for the weekly scheduling meeting participants.

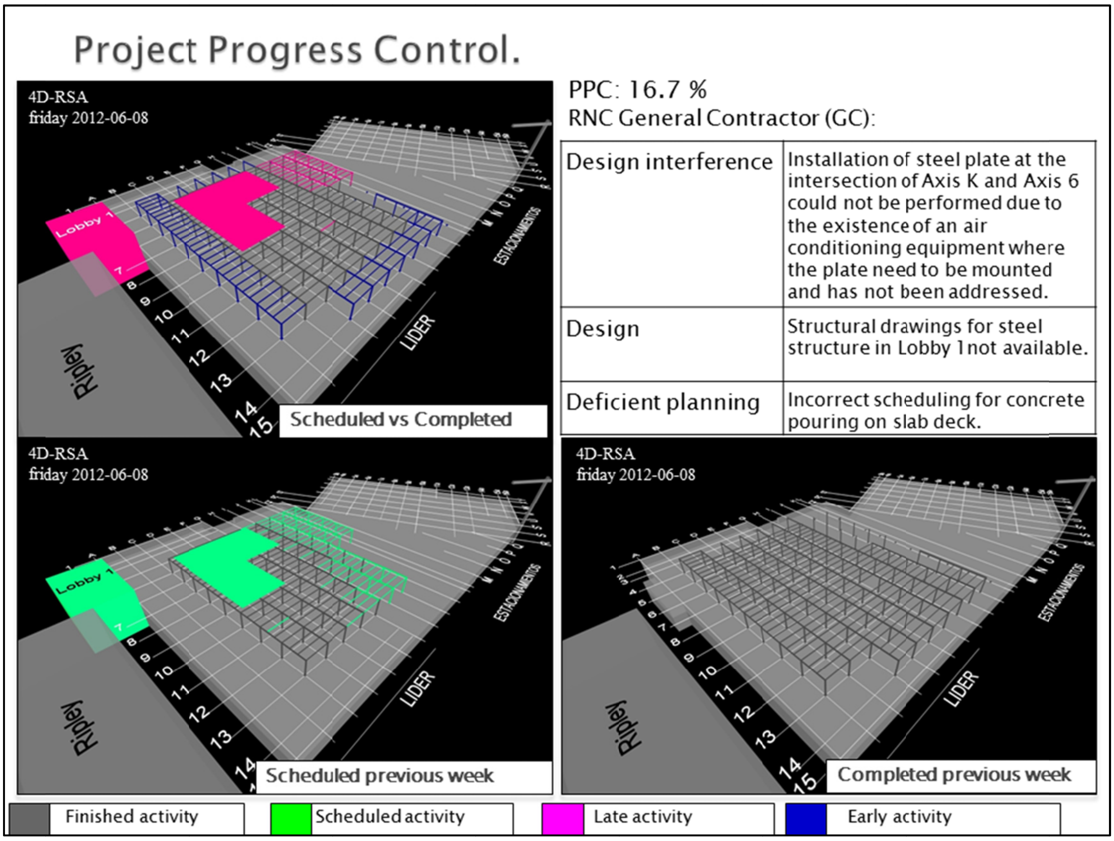

Figure 1: 3D/4D modeling proposal for the project progress control.

Figure 2 shows an example of how to use the proposed 4D model to manage and remove constraints for lookahead planning. There are four images: (i) on the upper left corner there is an image of the 4D model for the scheduled work for the Friday on the current week (same week when the planning meeting takes place), i.e., first week of the lookahead plan; (ii) on the upper right corner, the image is for the second week (Friday) of the lookahead plan; (iii) on the lower left corner the image shows the expected work to be completed by the third week (Friday) of the lookahead plan; and finally (iv) on the lower right corner the image shows the expected work for the fourth week (Friday) of the lookahead plan. The 4D elements for the models change colors according to the constraints that apply for each planned week in the lookahead plan. The sequence of images color the 4D elements according to the date committed to remove a constraint if the planning was strictly followed. For instance, we can see in Figure 2 that work in Lobby 1 (a cubic volumetric CAD element located on the A axis, between Axis 5 and Axis 7) has a design constraint if we want to schedule the week that ends on June 15th, 2012. If this design constraint is removed by that planned week, it is necessary to get authorization to work into the Lobby 1 "space", because the work will impact the operation of the stores located underneath that structure. Therefore, Lobby 1 goes from a design constraint (red) to an operation constraint (yellow). If the operation constraint is removed, there should not be an owner's constraint for the week ending on June 29th, 2012.

Table 2: Constraints associated to the owner and/or that it can help remove.

Constraint	Description	Examples
Design constraints	Those associated to the release of drawings, specifications, recommendations, or clarifications by the designers (e.g., architects, structural engineers, MEP specialists, etc.).	Inconsistencies between drawings and field conditions.
		Spatial interferences among different specialties.
		Missing details for connecting elements.
Operation constraints	Those associated with the disruption of the normal operation of the retail stores, or its associated facilities, such as parking lots, access, roads, gardens, etc.	Missing permits for provisional construction fences (for access control) at the lower level of the construction site.
		Missing authorization to disrupt and intervene (architecturally and/or structurally) retail stores or their dependencies.
		Missing authorization for night shift work.
Project definition constraints	Those associated with defining what is being built (number of floors, type of finishes, floor heights, type of space use, etc.)	Uncertainty regarding the exact location of the escalators.
		Unclear type and size of structural loads.

VALIDATION OF THE PROPOSAL FOR A BIM-LEAN APPROACH

The research was validated using a laboratory technique called "The Charrette Test Method" (Clayton et al., 1998). The technique was used separately with members of the project team, members of the Management and Control Department from the owner organization, and with a group of 5th year Civil Engineering students from University of Chile. We used this validation approach to test the usefulness of our BIM-Lean proposal with both seasoned practitioners (15 participants), and inexperienced students (19 participants) in order to discard the impact of experience and relationship with the project.

The validation is divided into two parts and each participant plays the role of the owner in a retrospective exercise for a meeting that took place on June 12th, 2012. In the first part, the participant answers a questionnaire using only the available documentation for the project team at that time (including among others: colored drawings used for activity sequencing, master schedule, and S-curves). In the second part, the participant answers the same questionnaire, but this time uses a complementary set of handouts as shown in Figures 1 and 2, that depicts our 3D/4D modeling proposal aimed at both project progress control and visualization and management of constraints under the owner's influence at the same time (June 12th). An additional set of questions is included in the second part to assess the usefulness of the proposed BIM-Lean approach.

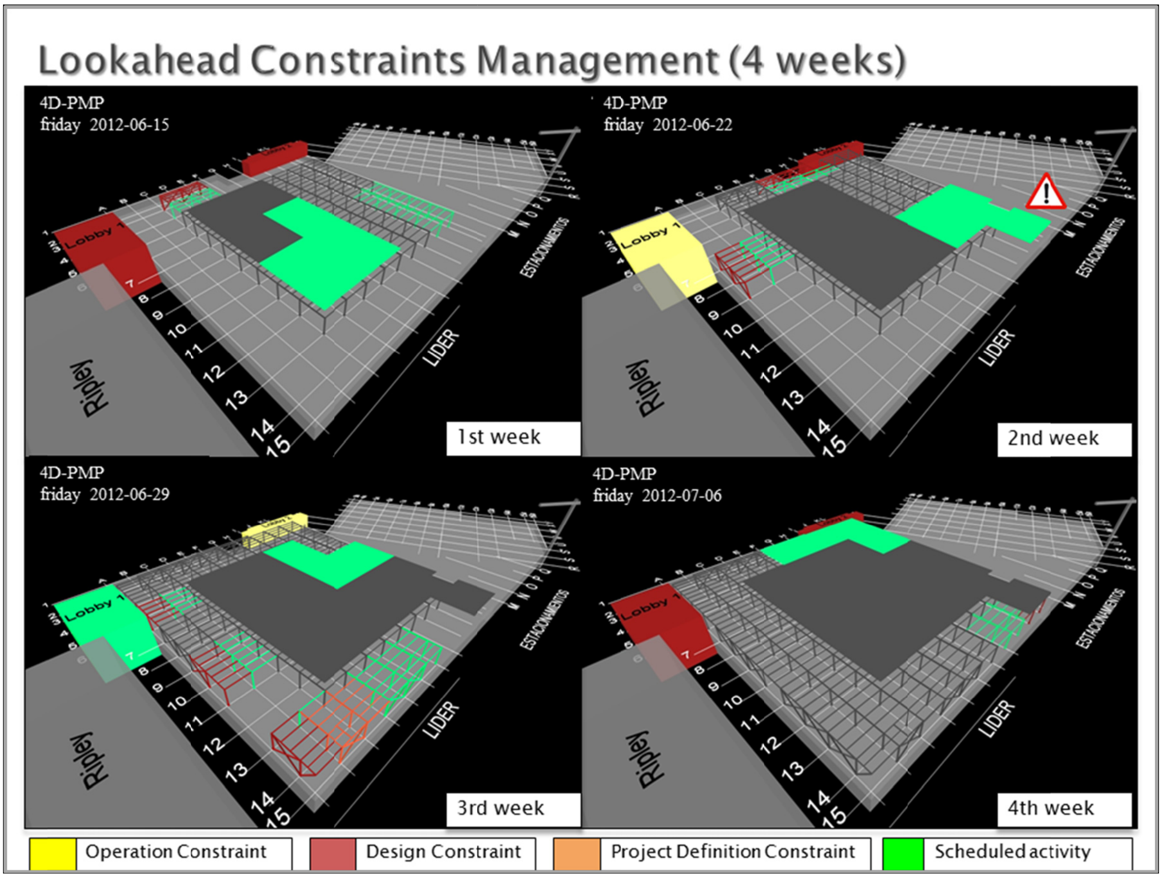

Figure 2: Proposal for the use of 3D/4D models to manage constraints in the lookahead planning.

The results from the validation show a remarkable improvement in the understanding of both the project progress control information and the information shown to help visualize and manage the constraints when using the proposed 3D/4D models (see Figures 3 and 4). This is true for the three groups tested (project team, owner's management and control department, and students).

The validation process also shows that both the information displayed for project progress control, and also the information displayed for constraints management is useful for all the three groups tested in the Charrette (see Figures 5 and 6).

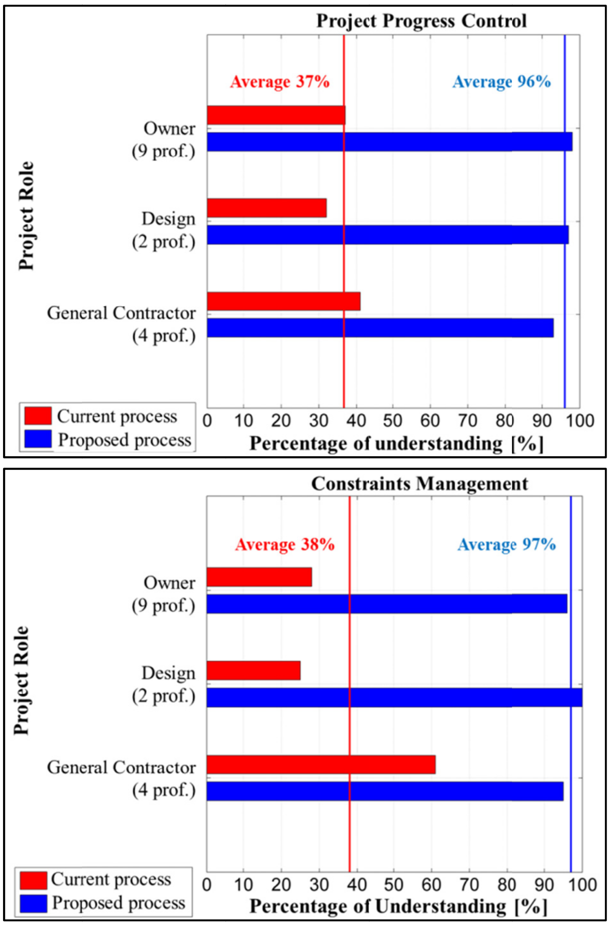

Figure 3: *Project Team* understanding about the project progress control information (top); and the constraints management (bottom).

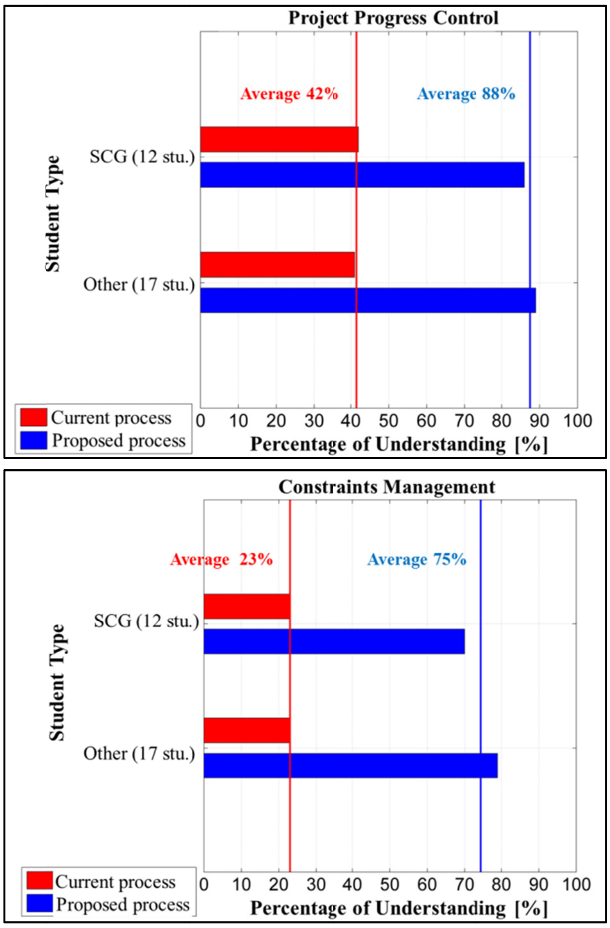

Figure 4: *5th year Civil Engineering Students* understanding about the project progress control information (top); and the constraints management (bottom).

*SCG: Structures-Construction-Geotechnical students.

**Other: Hydraulics or Transportation students.

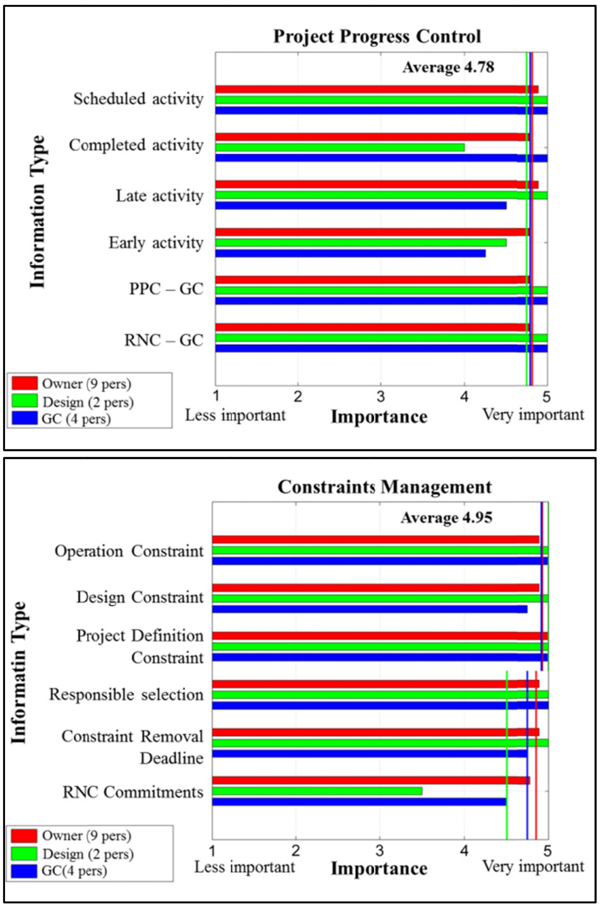

Figure 5: *Project Team* value of the displayed information about the project progress control (top); value of the displayed information for constraints management (bottom).

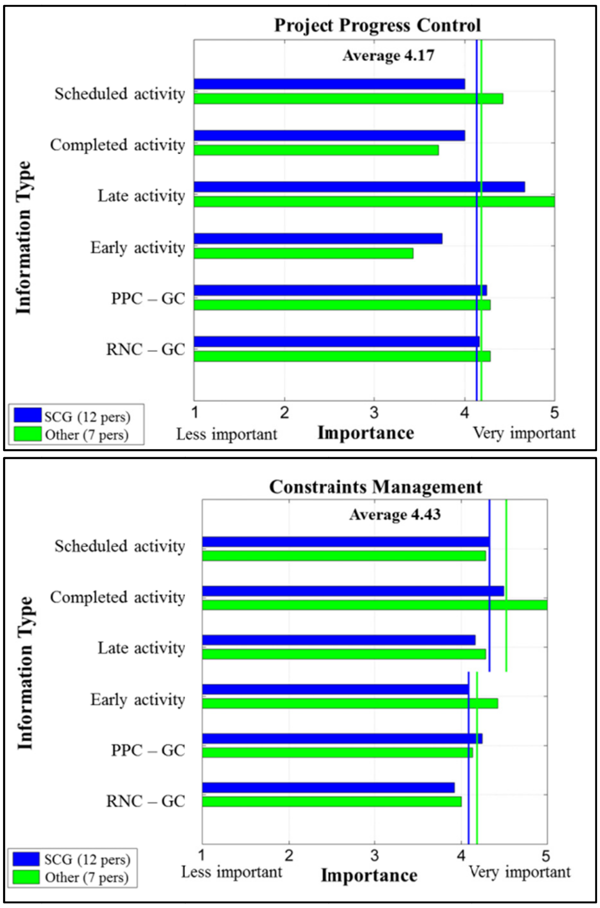

Figure 6: *5th year Civil Engineering Students* value of the displayed information about the project progress control (top); value of the displayed information for constraints management (bottom).

*SCG: Structures-Construction-Geotechnical students.

**Other: Hydraulics or Transportation students.

CONCLUSIONS

This work provides a concrete example or proposal of a BIM-Lean implementation aimed at improving the quality of information provided for both project progress control and constraints management of the owner. The proposal was formulated to respond to the field requirements of the case study, and accordingly, it was validated by project professionals, owner's representatives and advanced Civil Engineering students.

We distinguish two types of contributions from this work: contribution to knowledge and practical implications.

CONTRIBUTION TO KNOWLEDGE

To our knowledge, this is the first attempt to develop a classification for owner's constraints, i.e., those that the owner can directly manage and remove or help others to achieve it (see Table 2). Furthermore, these owner's constraints have been successfully displayed to project participants and inexperienced students using 4D models and they both have acknowledged their usefulness for project progress control and constraint management.

PRACTICAL IMPLICATIONS

The visual display of the owner's constraints in the lookahead planning using 4D models has helped them to better manage and remove such constraints. Additional 4D models have been successfully used to visually display the project progress control for the weekly work plan, and hence, to facilitate the planning meetings towards the schedule compliance.

LIMITATIONS

The case study had no formal schedule or at least was not openly discussed at the coordination meetings. Colored drawings were the main vehicle to share activity sequencing (planning); however, sequences were barely respected. Thus, our validation results can be coupled with the effect of formalizing the work plan required to first translate the colored drawings to actual schedules (Gantt charts) and then use them to build the 4D models. Seen from a different angle, our approach offers an opportunity to improve the project performance (reliable work flows) using LPS™ techniques even when there is a deficient planning process.

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