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INTEGRATED SCHEDULING PLATFORM BASED ON BIM AND LEAN CONSTRUCTION

Carolyne Filion[1], Fernando Valdivieso[2], and Ivanka Iordanova[3]

ABSTRACT

This paper presents an integrated scheduling platform (ISP) that was developed and implemented on a major health care construction project. This ISP incorporates both BIM and Lean Construction and provides a framework for developing the master schedule and the detailed schedule, as well as for monitoring the progress of on-site work. Although numerous studies present the advantages of integrating Lean Construction and BIM use, few on-site results have been quantified and published to date. This research therefore aims to identify and evaluate the impacts of using the ISP, as assessed by individuals who work on a construction site. The results obtained through interviews and questionnaires proved that using the ISP, was very positive for the project. Three major benefits were identified during the case study: planning was diligently updated, the information presented in the 3D models and in the visual schedules was always up to date and accurate, and all project stakeholders understood the schedule—which finally led to excellent project performance.

KEYWORDS

Building Information Modeling, Construction Planning, Lean Construction, Visual Schedule, Takt Planning.

INTRODUCTION

The artefact presented in this article—an integrated scheduling platform (ISP)—was developed to address a host of issues: theoretical planning does not reflect the reality of the job site, project stakeholders collectively lack proficiency with planning software, site crews spend an extraordinary amount of time each week planning and monitoring non-systematic schedules, planning is imposed on subcontractors, a lack of collaboration exists between stakeholders, and sharing planning information presents many communication challenges. These issues are usually addressed by ensuring an experienced and dedicated planning team is deployed in the project management structure (Slootman 2007). The mastery of planning software and the theoretical follow-up of deadlines provided by the planning teams satisfied the management teams, but the situation is different for the site teams. The theoretical information present in the schedules is rarely synthesized and adapted to the reality of the site crews, which creates

[1] Innovation Director – R&D and Special Projects, Pomerleau Inc., 500 St-Jacques, Montréal, Canada, carolyne.filion@pomerleau.ca, orcid.org/0000-0003-2559-504X
[2] Innovation Manager–APEX & Civil Operations, Pomerleau Inc., 500 St-Jacques, Montréal, Canada, fernando.valdivieso@pomerleau.ca , orcid.org/0000-0001-9741-8419
[3] Professor, Département de Génie de la Construction, École de Technologie Supérieure (ETS), Montréal, Canada, ivanka.iordanova@etsmtl.ca , orcid.org/0000-0002-4596-2604

a disconnection with worksite planning methods. In fact, the contribution of a team dedicated to planning within the management team, in itself, brings its share of communication problems between the teams and fortifies the silos. This statement is even more true when it comes to a mega-project where the organizational structure is more complex (Gupta 2015, Nyarirangwe and Babatunde 2019). To improve communication and partially resolve the challenges addressed, the BIM process is used to foster communication and Lean principles are integrated into practices to increase collaboration, but the complete solution is not combined with planning management practices.

To avoid this dissociation and respond to the issues, an artefact, integrating BIM and Lean principles for planning purposes was developed. Resulting from the combination of Action Research and Design Science Research, the ISP artefact is tailored to serve the various project planning phases and stakeholders involved. It provides a digital platform for the collaborative use of Last Planner System and Pull planning, integrated with BIM. To evaluate its impacts and to validate its efficiency, a case study was carried out on a major construction site during both the planning and the construction phases of the project.

The aim of the ISP application is to simplify the communication of schedules, facilitate the understanding of planning-related challenges, optimize construction sequences and ensure the schedule is updated in an efficient and seamless way for constant progress monitoring.

INDUSTRY PROBLEM AND THE CONTEXT THAT MOTIVATED THE DEVELOPMENT OF THE ARTEFACT

In construction management best practices, planning is a key element for project success. However, in the construction industry, the master schedules are often created to meet the client's requirements, while the site schedules are made in an unsystematic way by the construction crew. In fact, the construction industry has historically had a bad reputation in terms of cost, time and quality (Bertelsen 2003). A negative impact is brought also by the siloed and incoherent planning work, which does not give the project the added value that integrated planning can bring.

LITERATURE REVIEW

Although numerous studies in the last decade have presented the advantages of combining Lean Construction and BIM use, few on-site results of their integration have been quantified and published to date. The scientific literature reports positive and negative interactions between Lean principles and BIM (Sacks, Koskela et al. 2010, Sacks, Radosavljevic et al. 2010, Saieg, Sotelino et al. 2018) and gives detailed examples of improving construction through the combined use of Lean principles and BIM (Sacks, Korb et al. 2017). Bringing Lean principles to the construction site makes it possible to create added value for the client and enhances the stability of the workflow on the job site (Koskela, Ballard et al. 2002). Using Lean construction principles and applying Lean production methods to construction makes planning much more collaborative compared to conventional planning and scheduling practices.

In terms of planning, Lean Construction brings a vision focused on production and control. Planning concepts and strategies such as Takt planning—the German word "Takt" means cadence which, when used in the context of Lean Construction, addresses standardization, predictability and several other Lean principles (Haghsheno, Binninger et al. 2016, Binninger, Dlouhy et al. 2017). Production control charts and the concept of pull planning have also been developed following the principles of Lean Construction.

The BIM process, which has been described as “a verb or adjective phrase to describe tools, processes and technologies that are facilitated by digital machine-readable documentation about the building, its performance, its planning, its construction, and later its operation” by (Sacks, Eastman et al. 2018), is used in the planning methodology to help visualize and communicate and to structure project data.

Increased use of BIM has opened the door to the implementation of Lean principles in the construction industry. Although often used independently, the interaction between them influences their impact on each other. A total of 56 interactions between Lean principles and BIM functionalities were identified by (Sacks, Koskela et al. 2010), emphasizing that the full potential of this tie-in can be revealed only when their adoption is fully integrated. A recent publication gives examples of construction improvement through the combined use of Lean and BIM (Sacks, Korb et al. 2017), but no integrated planning, scheduling and monitoring platform incorporating BIM is reported.

METHODOLOGY

The methodology used in this paper combines Action Research (Azhar et al., 2010) with Design Science Research (Hevner and Chatterjee, 2010; Rocha et al. 2012) to define and develop the artefact—an integrated scheduling platform. The researcher was part of the planning team and could participate in all phases and iterations of the research project, as described by Salehi and Yaghtin (2015). The artefact’s efficiency was validated using a case study. To quantify the impact of the artefact and collect the results presented in this paper, superintendents and foremen from the construction site in question were interviewed and given questionnaires after 30 months of using the ISP.

DEFINITION AND DEVELOPMENT OF THE ARTEFACT

The definition and development of the artefact is presented in three steps: it will first be a question of establishing the needs to be met by the artefact, then its theoretical definition and finally its operationalization.

This ISP artefact was first developed in the context of the second phase of one of the largest health care construction projects in North America, totalling over 3 million square feet. Contractually and contextually, it presented a number of logistical challenges, performance targets and excessively optimistic delivery milestones. Since this project is long enough to be able to develop and implement an ISP and makes intensive use of BIM and Virtual Design and Construction (VDC) (Rischmoller, Reed et al. 2018, Sacks, Korb et al. 2017), and the construction team in place is very experienced and open to innovation, it was taken as an opportunity to develop and test the artefact.

ESTABLISHMENT OF THE NEED TO BE MET BY THE ARTEFACT

A list of needs was developed by the first author of this paper through collaborative discussions with the project management team and the site crew prior to the planning phase of this design-build project. This list represents the criteria that had to be met by the ISP artefact: (1) Planning updating needs to reflect the daily activities of the job site. (2) Individuals need to understand project planning regardless of their proficiency with the planning software. (3) The amount of time site crews invest weekly to monitor schedules needs to be minimized. (4) Meetings and communications between foremen to update planning need to be structured and streamlined. (5) Subcontractors need to be included in schedule development to ensure they are committed to the schedule. (6) There needs to be greater collaboration on the job site by having discussions and ensuring a transparent process for all stakeholders. (7) The sharing of data to update planning needs to be streamlined and automated. (8) Clear and simplified visuals (including generated with BIM) need to be used to communicate the schedule to site crews.

THEORETICAL DEFINITION OF THE ARTEFACT

The resulting artefact, the ISP, proposes an application framework for using a variety of tools that are heavily inspired by Lean Construction principles, the BIM process and practices the project team had already adopted.

To create the master schedule

The first part of the framework proposed in the ISP pertains to creating the master schedule. The master schedule is produced using project input data, such as distinctive features, constraints, opportunities and the company's business strategies. Once this basic data about the project has been gathered, the framework sets out four distinct phases for creating the master schedule: the organization phase, the development phase, the validation phase and the planning optimization phase. Once the four planning phases are completed, the master schedule serves as a solid foundation to ensure BIM and Lean Construction are incorporated during the construction phase. Each of the phases—Organization, Development, Validation and Optimization—has diverse needs and uses different tools and principles as shown in Figure 1.

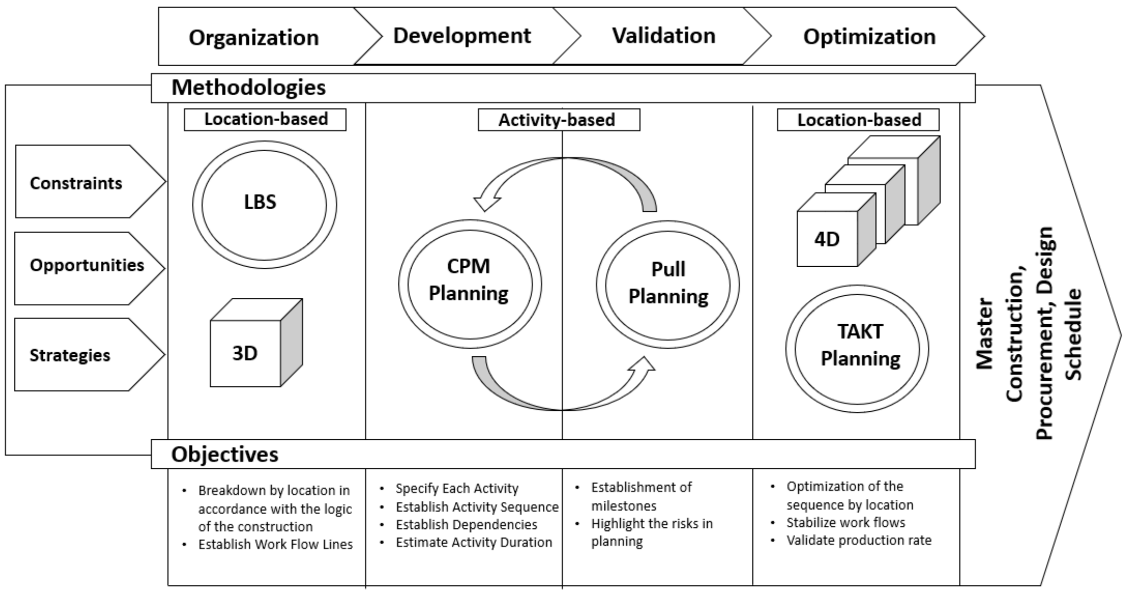

Figure 1: Framework for creating the master schedule

In the following paragraphs, these four phases of the cycle are presented in more detail:

Organization: To ensure that information is organized, the project needs to be segmented not only by work breakdown structure (WBS) for planning, but also by location breakdown structure (LBS). According to Kenley and Seppänen (2009), "location production focuses on the use of locations as the unit of analysis and tasks as the unit of control". It is essential that the site crew be involved in this segmentation phase to confirm the zones are realistically defined, accurately represent the construction sequencing strategy, and stabilize output and workflows.

Development: The critical path method (CPM) is used for planning development, meaning that construction sequences are developed, logical connections between activities are identified, and the duration of activities is determined to create the different sections of the master schedule. The location-based structure (LBS) that was previously determined with the site crew is followed when initiating the sequences, and the CPM governs the details of the schedule. It is during this phase that the schedule takes shape, following the differentiation of production-oriented planning methodologies and critical path analysis planning methods, as underlined by Kenley and Seppänen (2009).

Validation: The pull planning method, grounded in lean construction principles, is used to ensure the information structured and introduced by the CPM is validated. Pull planning encourages collaboration and ensures planning is tested, the main contractual milestones are validated, and the most critical activities are highlighted. During this phase, construction sequences are confirmed by the specialized contractors; and challenged to verify their compliance with the time constraints of the project. Validation can also be assisted by 4D simulations.

Optimization: Lastly, Takt planning is used to validate planning, productivity levels and schedule workflows to ensure planning is optimized. This key step in the master schedule creation process can undergo several iterations to ensure location, labour and productivity constraints are fully controlled.

This is how the master schedule for this project was created, and this foundation made it possible to implement the ISP combining Lean Construction and BIM on this project's construction site.

To develop the detailed schedule

The detailed schedule is developed from the master schedule once the construction phase has begun and project collaborators (subcontractors and design professionals) have joined the team. Details provided by the experts of each discipline are added to the schedule progressively—depending on how quickly contracts are awarded—and illustrate the detailed construction sequence strategy. Once the master schedule is submitted and approved, the same framework is adapted and used to ensure the detailed schedule is developed in collaboration with partners not only during the collaboration phase, but throughout all the planning phases (Figure 2).

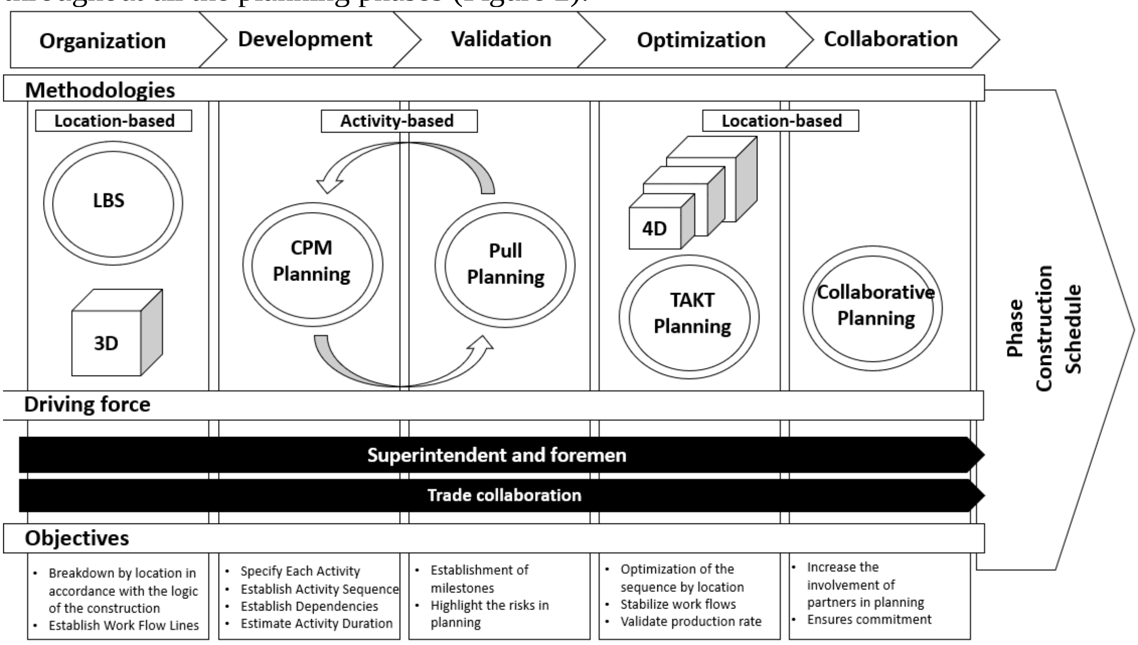

Figure 2: Framework for developing the detailed schedule

The site foremen who will directly organize the work on site must be involved to achieve better planning results and ensure the construction sequences proposed in the detailed schedule are realistic and approved by the main stakeholders. This involvement, inspired by the "decide by consensus" Lean principle derived from Toyota's practices (Liker 2004), makes it possible to leverage the experience and opinion of several discipline experts when developing sequences and deciding on the duration and interrelationship of construction activities. Taking all available options into consideration when developing the detailed schedule considerably increases the success rate of obtaining the best solution or construction sequences, as the case may be.

The framework requires partners' participation throughout the process. The project managers of the various disciplines are asked to participate in the first four phases, namely Organization, Development, Validation and Optimization, to ensure required contractual milestones are met. During the last phase, Collaboration, the trade site crews are also involved. The aim of this phase is to work with the foremen of the disciplines in question and ensure they actively participate in the planning session in the interest of increasing the success rate of obtaining a realistic schedule and increasing partners' involvement in and commitment to planning.

To produce the three-week lookahead schedule

The three-week lookahead schedule is produced by highlighting the activities to come in the next three weeks in the visual schedule of the phase in question. The phase's visual schedule is automatically extracted from the detailed schedule and represented by production control charts—a location-based tool designed to show the status of the project on one or very few pages (Kenley and Seppänen 2010).

The visual schedule, as shown in the Figure 3, is created by extracting data from the detailed schedule, which is sufficiently detailed for use on the construction site.

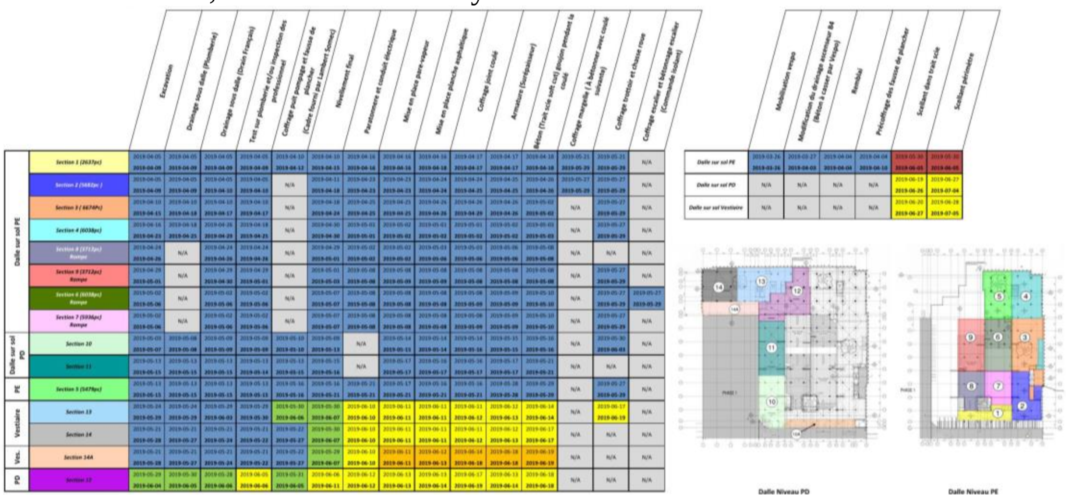

Figure 3: Graphical representation of the phase schedule with color indicators showing upcoming activities in the next three weeks

OPERATIONALIZATION OF THE ARTEFACT

Once the construction work has begun and the detailed schedule is in development, the ISP is implemented, making it possible to meet the requirements listed at the beginning:

- Ensure the information in the visual schedules and in the Takt planning matches the information in the detailed schedule and the master schedule.

- Make sure a visual schedule is automatically produced from the detailed schedule.
- Make sure the information in the detailed schedule and work progress information is applied to the BIM models and shown in 4D simulations.
- Ensure the maximum number of people understand the schedules, regardless of their proficiency with the planning software and the Gantt chart.
- Increase stakeholders' degree of confidence, knowing that all stakeholders are working with the same information during design and construction.
- Make it easier to update schedules and reduce the amount of time required to do so by proposing the option of automating the updating of activity progress using a mobile application.

As shown in Figure 4 – operationalization of the digital artefact, once the master schedule and detailed schedule have been developed with partners during collaborative planning

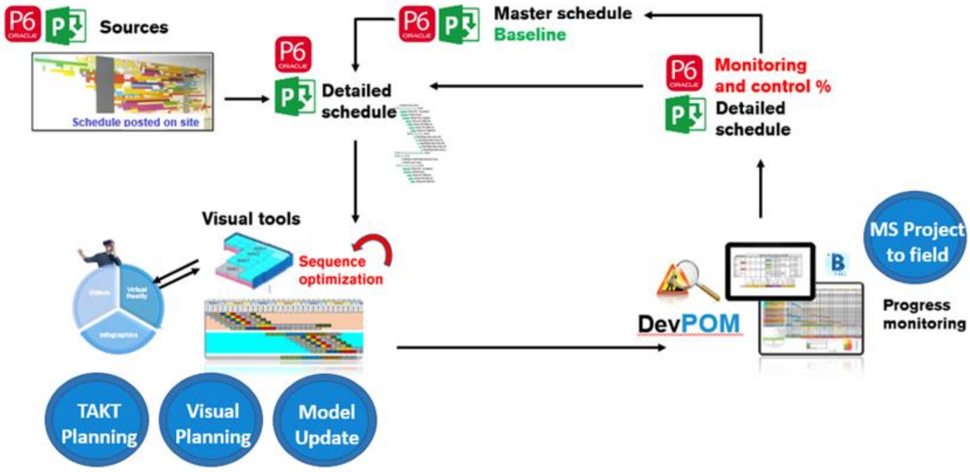

Figure 4: Integrated scheduling platform – operationalization of the digital artefact

sessions, the solution proposes to automatically extract from the detailed schedule visual schedules (by phase – to highlight three-week lookahead planning) with colour coding to indicate the progression of work. These two types of automatically generated schedules make it possible for the site crew and project stakeholders to visually understand planning and the progression of work. Furthermore, these two types of schedules are accompanied as necessary by a 3D BIM model and a 4D simulation updated with the latest information from the detailed schedule.

The last step of the ISP makes it possible for foremen to easily share the progression of work in their zone using a mobile application and for the information to automatically be logged in the detailed schedule and the master schedule.

This workflow ensures that work progress percentages are sent directly from the job site to the detailed schedule, the 3D BIM models and the 4D simulation. This flow of information makes it possible to generate in real time a simulation that represents the sequences as they are built.

ASSESSMENT OF THE ARTEFACT – A CASE STUDY

The ISP was developed prior the project planning phase of the mega hospital project, before the design and construction phases, to ensure it would be integrated and tested on the case study by the time the first draft of the preliminary master schedule was produced. This guaranteed that the construction team would follow the same structure for the entire duration of the project and for all phases. Furthermore, since the superintendents of the team assigned to the project were already used to collaborative planning, we included them in artefact development to cement their buy-in. This also allowed for the site crew, led by the superintendents involved in solution development, to be trained on the ISP very early in the planning process. Interviews were conducted and questionnaires distributed with the objective to assess the impact—of using BIM and Lean Construction together, and to measure the effectiveness of the ISP used during 30 months on this project. Members of the site crew (who used and applied the ISP on a daily basis) assessed and commented on the artefact's impact and shared their feedback with us.

DESCRIPTION OF THE PARTICIPANTS

A total of eight men, 63% of whom were foremen and 38% of whom were superintendents, participated in this case study. The average number of years of experience of participants who held a construction project management position was 13 years. The average number of years of experience of the superintendents involved in this project was 20 years. In total 5 foremen and 3 superintendents were interviewed. In terms of past experience, 62% of participants (100% of the superintendents) said they had already used a tool or methodology that incorporated one or more of the key principles of Lean Construction.

MATURITY OF THE PROJECT TEAM

The participants' self-evaluations indicated that, at the beginning of the project, the superintendents considered their level of familiarity with Lean Construction to be average (6 out of 10 on average), as the foremen (5 out of 10). To better understand the team's level of maturity and experience, we asked the 62% of participants who said they had previously used a tool or methodology that incorporated one or more key fundamental principles of LEAN Construction to identify which tools or methodologies they had previously used. Of the participants had previously used a tool or methodology incorporating key principles of Lean Construction, all said collaborative planning was a technique heavily inspired by Lean Construction, half said they had previously used visual planning to improve site crews' understanding of planning, and one had previously used 4D simulations to improve the understanding of planning. Thus, we can conclude that participants did not have to overcome a very steep learning curve to apply the ISP.

THE PROJECT TEAM'S ASSESSMENT OF THE ISP

To begin with the project team's assessment of the ISP, all participants were asked at the end of the project to assess the artefact's impact on the project after 30 months of use. On a scale of -5 to +5 (with -5 meaning negative impact, 0 meaning no particular positive impact and +5 meaning positive impact), more than half of the participants chose the highest positive impact (+5). The average assessment value was 4.9. The subsequent interviews conducted with participants allowed us to explore why this assessment was so positive. According to participants, the ISP ensured that: (1) Planning was diligently updated throughout the project; (2) The information presented in the models and visual schedules was accurate and up to date; (3) All project stakeholders understood the schedule, which led to greater trust and better communication. In the following paragraphs, these three major benefits are presented with more detail:

Planning was diligently updated: According to participants, the artefact's structure imposed greater diligence in terms of the frequency of updates to planning information. The upsides of this diligence imposing daily meetings and weekly updates were that it ensured planning was done carefully, prompted question periods regarding scheduling, and made sure there were stopping points to modify and adjust construction sequences, thus ensuring the site crew was acting proactively rather than reactively. The vast majority of participants also said that the consistency and increased diligence the ISP required represented a significant change to their work routine. The time allocated for planning during a work week became much better distributed over the week, and planning meetings became much shorter. Rather than organizing one long, intense work session per week, during which foremen and superintendents typically had difficulty staying on task and working efficiently for the whole meeting, participants appreciated the fact they could do the exercise more frequently and in a shorter, more concise format. As one participant explained, “At the end of the week, I feel freer and in control of planning. Implementing this platform makes me feel like I have one less weight on my shoulders.” In fact, participants acknowledged that although they spent the same amount of time planning each week, the frequent updates lightened their workload, and in the end, they felt relieved.

The information presented in the models and visual schedules was accurate and up to date: The ISP also enabled a greater degree of confidence in the accuracy of the information displayed in the BIM models, 4D simulations and the visual schedules. Since the information is accessible to everyone as soon as it is updated and available at any time in a model viewing and document management platform, all stakeholders can always consult the most up-to-date information. Some participants also highlighted how quickly information became available after it was updated. In short, participants stated that one of the artefact’s major positive impacts on the project was the degree of confidence it gave people in the information available on the document viewing and management platforms throughout the project.

All project stakeholders understood the schedule: Lastly, the third major positive impact that was mentioned by participants during the interviews centred around how easy it was to understand the information produced by the visual planning process. The fact that very simple and clear visuals were used to make planning more accessible ensured all members of the site crew and professional teams as well as the client’s representatives, regardless of their familiarity with reading a Gantt chart or schedule, could access the information, and quickly and easily understand the planning, as complex as it was. This simplification of information fostered a better understanding and better communication, and in turn facilitated the achievement of the project’s key milestones.

Since the ISP ensures that the information displayed in the master schedule given to the client always matches the information in the schedules used by professional partners and subcontractors on the construction site, it was noted that stakeholder collaboration was positively impacted. Also, it had a positive impact on stakeholders’ level of trust in one another and on their collaboration with one another. The questionnaire given to participants indicated greater collaboration with each type of stakeholder, and notably better collaboration with subcontractors.

The relationship and level of trust and therefore collaboration between a general contractor and subcontractors can easily be negatively impacted over the course of a project by a lack of transparency and communication between the parties. Implementing the ISP early in the project enabled subcontractors and partners to quickly trust the project planning since they were involved in and consulted on the project right from phase schedule development. Their participation in planning and in toolbox meetings made it possible to build this trust and improve the team’s synergy.

Furthermore, since the ISP made it much easier to read the planning documents, it was noted that many subcontractors quickly bought into the artefact and followed the visual schedules, as the latter made it possible to ensure everyone understood the information. It is important to mention that many subcontractors and workers, despite their experience, cannot read Gantt charts and have difficulty identifying planning risks for their own team when the information is not presented in a concise visual format.

IMPACT ON PARTICIPANTS' LEVEL OF TRUST IN MEETING THE MILESTONES

After assessing the artefact's impact on the project and on stakeholders' level of trust and collaboration, we looked at participants' level of trust that the contractual milestones would be met, which is a key factor for the success of the project. Participants measured the artefact's impact on their level of trust in meeting the milestones, on a scale of -5 to +5 (-5 meaning negative impact, 0 - no particular impact and +5 - positive impact). The assessment value was between 4,75 and 5 for 90% of the participants. Thus, we can conclude that the ISP had a very positive impact on participants' level of trust that the contractual milestones would be met and work would be completed on time. The subsequent interviews revealed the following main factors impacting participants' level of trust: (1) Partners were more involved in planning, which increased the accuracy of schedule sequences. (2) Stakeholders were much more willing to collaborate due to the ISP increasing transparency and communication on the construction site. (3) Lean Construction principles were applied to ensure location-based planning, thereby leading to subcontractors having a specific amount of time in a specific zone and limiting the overlapping of activities in a given zone. (4) A collaborative approach was used to develop the detailed schedule. (5) Just-in-time delivery to the site was used. (6) It was easy to make changes in the schedule and see their impacts on delivery milestones.

These factors increased participants' level of trust that contractual milestones would be met and were key to improving stakeholder relations on the construction site. To summarize, the impacts of implementing this ISP were very positive for the team. All participants stated during the interview that they would use this artefact on their next job and that they believe it provided a structure that was critical to the success of the project.

CONCLUSION

This research has studied the impacts of using the first version of the ISP on a job site. It currently focuses on the general contractor's point of view and paves the way for further research to quantify the direct and indirect impacts on the work of design professionals, subcontractors and suppliers. Implementing this artefact on a major health care construction project carried out by a large construction and design-builder company has proved to be very advantageous. As an output of the research, three major benefits were identified during the case study: planning was diligently updated, the information presented in the 3D models and visual schedules was always up-to-date and accurate, and all project stakeholders understood the schedule. The fact that the delivery milestones were achieved, despite how optimistic they were, attests to this artefact's positive impacts. In the future, a larger study will be conducted across a dozen projects completed by the company where the ISP is deployed. This larger research scope and the feedback from all site crews and management teams will define the improvements that need to be integrated in the next version of the artefact. Incorporating innovation in this general contractor's planning practices is in line with an innovation strategy that focuses on using VDC as a turning point to integrate new ideas and technologies as the main pillars of project management in order to add value to the project and deliver it on to the client.

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