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COLLABORATIVE PLANNING OF SUBCONTRACTORS USING THE LAST PLANNER SYSTEM AND BIM: A CASE STUDY ON A GAS SUBCONTRACTOR IN REPETITIVE HOUSING PROJECTS

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ABSTRACT

The objective of this study is to adapt the Last Planner System (LPS) for managing subcontractors in natural gas installations within repetitive housing projects, using BIM technology for enhanced modeling and efficiency. Our methodology was applied to a large-scale, multi-family, low-cost housing project in Lima, Peru. Through this application, we achieved high Percent Plan Complete (PPC) values and improved collaborative planning practices. This paper makes distinct contributions to the subcontractor management literature: (1) it demonstrates the practical integration of LPS with BIM to streamline subcontractor activities in a real-world setting; (2) it offers a novel approach for determining optimal Takt Time Planning for daily and weekly schedules, enhancing the predictability and reliability of subcontractor work; and (3) lessons learned from the implementation provide a roadmap that can be adapted to other subcontractor management scenarios.

KEYWORDS

Last Planner System, subcontractor management, gas facilities management, continuous improvement, BIM.

INTRODUCTION

The efficient management of subcontractors turns into a challenge in contracts with fixed prices and very short terms. Non-conformances due to poor deliverables are common, generating delays and cost overruns for all parties involved, especially for the main contractor (Akintan and Morledge, 2013). It is a very common practice in construction projects that the main contractor contracts subcontractors to transfer cost and deadline risks to it with the aim of not losing money. However, it is still necessary to analyze the relationship of subcontractors and contractors to improve their performance (Ribeiro et al., 2017). The Last Planner System (LPS)

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is a production system that shows multiple workflows, identify deficiencies or wastes and promote continuous improvement (Aslam et al, 2020). In addition, LPS is a control system with the principal goal to reduce variation and uncertainty in construction activities (Hamzeh et. al, 2012). In addition, LPS is a collaborative tool that promotes continuous flow, teamwork and reliability (McConaughy and Shirkey, 2013). LPS encourages people to coordinate multiple activities and resolve problems with team agreements (Pavez and Gonzalez, 2012). However, there is still little information about successful results in the management of subcontractors. (Akintan and Morledge, 2013). The most frequently used system to implement the Lean philosophy in project works is the LPS (Smith and Ngo, 2017) and there is much evidence that projects with a Lean approach allow contractors to have better productivity, deadlines, and prices, among other indicators (McGraw Hill, 2013; Hasle et al., 2012). Nevertheless, with no adequate education and training, there could be resistance to change in subcontracting companies, and they would refuse to use Lean systems (Emuze et al., 2021).

With the implementation of Building Information Modeling (BIM) and Lean Construction, the AEC industry is making an important transformation. These are different initiatives, but both are making a great impact on the industry (Heigermoser et al 2019). According to recent studies the LPS is used in combination with 4D models in order to improve the project progress, and to prepare and show a better visualization during the planning meetings (Sacks et al., 2011; Toledo et al., 2014). The use of LPS becomes a potent tool when practitioners incorporate automated BIM workflows. With this incorporation, decisions and feedback are based on optimized information from the BIM models for the constrain analysis, identification of tasks, sizing, and sequencing (Gerber et al., 2010). Although Building Information Modeling (BIM) is utilized in this project for enhanced visualization and planning, the main focus of our research is on the application of LPS. We explore how LPS can be adapted to the unique demands of subcontracting within the construction sector, particularly in projects involving repetitive tasks like those seen in housing developments.

The Last Planner System (LPS) has been increasingly recognized for its potential to enhance subcontractor management in construction projects. LPS, a lean construction tool, focuses on reducing the variability in production planning and increasing the reliability of scheduling, which are critical for the efficient management of subcontractors. By involving subcontractors in the planning process, LPS facilitates improved communication and coordination, which helps in aligning their work with the project's main schedule and objectives. This collaborative approach not only mitigates the risk of delays but also enhances the overall project execution by integrating subcontractor inputs early in the planning phase. Despite its advantages, the literature reveals several gaps in the application of LPS in subcontractor management. Firstly, there is limited empirical evidence on the quantitative benefits of using LPS specifically for subcontractor management as opposed to general project management. Secondly, the strategies for effectively integrating technology, such as Building Information Modeling (BIM), with LPS to optimize subcontractor performance are not well-documented. These gaps underscore the need for more targeted research to explore and validate the use of LPS in enhancing subcontractor management across different types of construction projects. Therefore, the main objective of this research is to propose a method that adapts the LPS to the subcontract management, as well as to apply it for subcontracting natural gas installations in a highly repetitive housing project, which was modelled by using BIM technology.

LAST PLANNER SYSTEM (LPS)

LPS is a collaborative stakeholder system that combines tools, techniques, and practices to manage projects by reducing variability (Ballard, 2000); LPS proposes that planning and programming be considered as a system, performance be measured, and programming errors be analyzed, identifying the root causes of non-compliance, and adopting corrective measures, evaluating their impact (Ballard, 2000; Daniel et al., 2017). During the planning phase, LPS recommends that the level of detail for every activity should be increased as the execution date approaches; collaborative meetings, called Pull Planning, include subcontractors and contractor support areas (Verán and Brioso, 2021).

The LPS elements are the following: Master Planning: the general schedule is developed, deadlines and milestones are agreed, and construction processes are defined (Ballard, 2000). Pull Planning Phase Session: a meeting where all the support areas and subcontractors have to identify the "handoffs" and agree on the Takt Time Planning (TTP) and sectorization; TTP consists of defining the production units to be executed on a daily basis and their sequence; Sectorization consists of dividing the work areas or volumes into several sectors to create a balanced production line and define the limits between sectors. Agreements must be fulfilled as part of the subcontractor's contract (Elfving, 2021; Murguia and Brioso, 2016); Lookahead Planning: it is planned by time windows that usually have some weeks according to their variability (Ballard, 2000). Constraint Analysis: every week of the Look-ahead is analysed. A constraint can be defined as a previous requirement of an activity that can stop the production flow if it is not considered (Ballard, 2000; Brioso, 2011). Weekly Work Planning: compliance with the first week of the Lookahead is optimized and buffers are used according to variability and complexity (Ballard, 2000). Daily Programming: the maximum scheduling level is reached, and the use of common equipment is agreed with subcontractors (Ballard, 2000; Brioso, 2011). Learning (Reliability Analysis): performance measurements are made for every task and subcontractor, the root cause of a non-compliance is analysed, and corrective measures are adopted as soon as possible. LPS measures the weekly and daily plan performance through the percent plan complete (PPC), which is the number of completed tasks divided by the number of scheduled tasks (Ballard, 2000).

SUBCONTRACTORS MANAGEMENT AND LAST PLANNER SYSTEM

There is little information about subcontractors' management in projects that implement the LPS. A study shows that the perception of subcontractors about phase collaborative planning is positive, and that teamwork and a sense of collaboration are developed (Ribeiro et al., 2017). Other research shows that there are still barriers in the implementation of LPS in finishing subcontracts in the USA (Smith and Ngo, 2017). LPS cannot be implemented until changes are made through education and training (Emuze et al., 2021). Regarding the application of LPS and Lean concepts in the gas industry, there is very little information. A study proposes the use of the collaborative tool First Run Studies to Develop Standard Work in the ongoing remodeling of a Liquefied Natural Gas Plant (Hackett et al., 2015). On the other hand, another study explains that the use of Lean tools could be useful in Offshore Oil and Gas Construction (Lerche et al. 2019). In addition, other research indicates that the application of Lean concepts and tools in the oil and gas industry is still undeveloped and lacks details; however, it proposes that digital transformation and Lean concepts could complement each other to improve the collaborative engineering review process at Oil and Gas EPC Projects (Matta et al. 2022). Nevertheless, no results have yet been presented on the application of LPS in the execution of gas subcontracts in urban areas. Additionally, in recent years, various studies have been published showing that LPS has been implemented by different general contractors in Peru with successful results, showing performance indicators of the structure and finishing phases (Brioso et al., 2016; Brioso and Calderon-Hernandez, 2019). However, no information on subcontracts for gas installations in building projects in urban areas has been published.

BUILDING INFORMATION MODELING (BIM)

BIM is a work methodology based on 3D modelling that offers the necessary information and tools to stakeholders to plan, design, build and manage buildings and infrastructures (Cortijo et al., 2021). By the year 2003, the General Services Administration (GSA) of United States with the support of the Public Buildings Service (PBS), created the National 3D-4D-BIM Program. Then, in 2007, the GSA established, for all the major projects, that spatial program BIMs be the minimum requirements for submission to the Office of Chief Architect (OCA) (Edirisinghe and London, 2015). In addition, in the year 2007, the National Building Information Modelling Standards of United States (NBIMS-US) published the first BIM standards. After this publication, BIM protocols were used as addendum for construction contracts with the support of the American Institute of Architects (AIA) (Sarı and Pekeriçli, 2020). By the year 2007 appeared similar initiatives in the United Kingdom AEC industry. The UK government published Publicly Available Standards (PAS) to describe BIM services (Sarı and Pekeriçli, 2020). A few years later, in 2016, the government established that level 2 BIM is obligatory for all public projects. Also, the UK government developed a BIM committee to support contractors during the transformation process to BIM. Besides that, in order to accomplish embrace BIM in the projects, the British Standards Institute (BSI) defined information sharing standards called PAS 2292:2 and the UK government created a roadmap for public projects. (Edirisinghe and London, 2015).

BIM integrates the 3D model of a project with geometric and/or parametric information and is described as the digital representation of the physical and functional characteristics of any object (Sacks et al., 2018). BIM improves the projects design, encourages an efficient workflow and reduces errors during the process (Lévy 2011). The 3D model for a construction project has to be linked with data building elements or components. The information of elements or components are obtained from the level of development (LOD) specification (Lévy 2011). The BIM approach is based on collaborative planning, reasoning, discussion of ideas, decision-making, transparency, improvement of understanding, among other factors, which help employees develop soft skills (Brioso et al., 2022).

The use of Lean Construction and BIM is not restrictive between each other. The interaction of Lean and BIM permits different opportunities to make an efficient workforce and an effective process in the construction projects (Oskouie et al. 2012, Hamdi and Leite 2012, and Dave et al. 2013). An important contribution of the interaction between Lean and BIM is the LC-BIM matrix, which includes 56 positive interactions that support waste elimination and adding value concepts (Sacks et al. 2010). Literature describes some steps for the interaction between LPS and BIM. These studies presents a framework that integrates BIM with LPS at Master planning Level, Lookahead Planning and Weekly Work Planning in order to seek the reduction of waste and to increase collaboration with the project stakeholders (Bhatla and Leite 2004). Also, these studies describe the interactions between LPS and BIM functions, for example: Master Plan with 4D models; Lookahead Planning with Request for Information, Weekly Work Planning with Systematic registration of demands for information, among others (Garrido et al. 2015). Another study presented the advantages of the interaction between LPS and BIM for mechanical, electrical, plumbing and fire protection functions (Tillmann and Sargent, 2016). In this study, significant interaction between LPS and BIM were identified, which are presented in this case study.

METHODOLOGY

Figure 1 shows the research methodology. It is proposed to adapt the LPS processes to manage a natural gas subcontractor in a highly repetitive housing project located in the city of Lima, Peru.

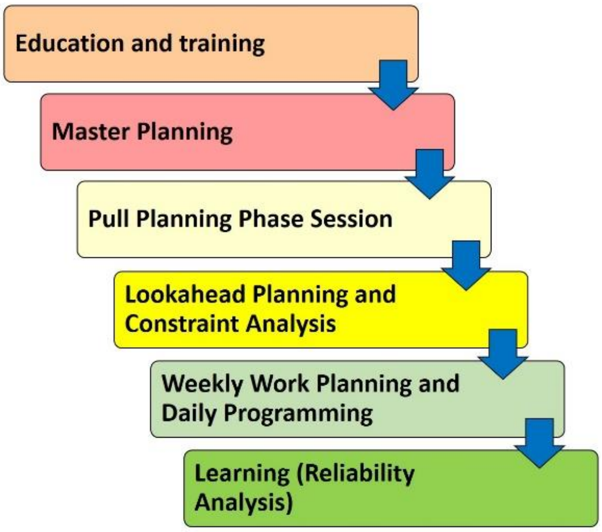

Figure 1: Research methodology

The steps are the following:

1. Education and training: subcontractor personnel, including foremen and site managers, were provided with a series of training sessions on the principles of the Last Planner System (LPS). These sessions included interactive workshops and simulations to demonstrate the practical application of LPS tools such as Pull Planning and Lookahead Planning. The aim was to ensure that all team members understood how to implement these methods in daily construction activities to improve scheduling accuracy and reduce waste.
2. Master Planning: The project's master schedule was developed using collaborative input from all key stakeholders, including subcontractors. This stage involved the use of BIM software to visualize project timelines and critical milestones. By integrating subcontractor schedules into the master plan, we aimed to align all activities and minimize conflicts in the workflow.
3. Pull Planning Phase Session: During these sessions, subcontractors and the main contractor's management team met to discuss and agree on the workflow and sequence of operations. The use of BIM models helped to identify potential logistical issues and sequence tasks effectively. These meetings were essential for establishing a clear and shared understanding of the project's operational demands and for enhancing the temporal and spatial coordination of tasks.
4. Lookahead Planning and Constraint Analysis: Subcontractors were required to submit detailed four-week lookahead plans, which were reviewed weekly to identify and address potential constraints such as resource limitations or scheduling conflicts. This proactive approach allowed for timely interventions, ensuring that project milestones were met without delays.
5. Weekly Work Planning and Daily Programming: Detailed daily work plans were created, specifying the tasks to be completed, the resources required, and the expected outcomes. These plans were adjusted based on real-time feedback and project developments. The daily updates provided a mechanism for continuous improvement and allowed for flexibility in response to on-site challenges..
6. Learning (Reliability Analysis): At the end of each week, a review session was conducted to assess the accuracy of the work planning and the reasons for any deviations from the plan. This analysis helped in identifying consistent patterns of issues that could

be addressed in future cycles. This stage was crucial for learning from experiences and for making systematic improvements to the planning and execution processes.

Regarding the case study, the main construction company has over 20 years of experience constructing buildings of all kinds in Peru, including massive affordable housing projects. In addition, the company has over 15 years of experience implementing LPS concepts and tools. On the other hand, the natural gas subcontractor has 20 years of experience and is the main gas supplier in Peru. It has also participated in projects where LPS has been implemented; however, it is usually informed about the general contractor's schedule at short notice which consequently leads to inefficiency and very low PPC values, with 70% on average.

The methodology was applied to a massive multi-family affordable housing project, which was modeled with BIM technology, Revit 2021 software. The project is located in the city of Lima, Peru, with a built area of 7,372 92 m2. It consists of 4 housing buildings with 16 floors, 512 apartments of 49.50m2 and 50.40m2 of covered area. The structure of every building is made of reinforced concrete and has low-cost finishes and installations. Figure 2 shows the typical floor plan of a building.

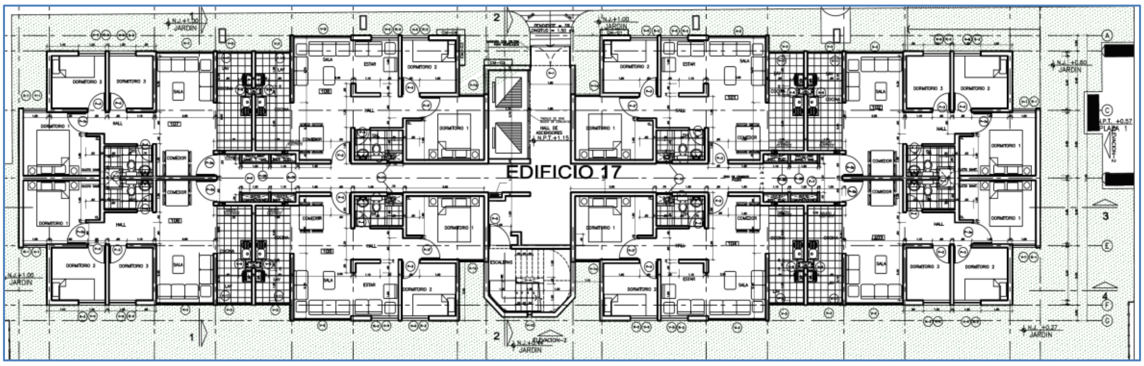

Figure 2: Typical floor plan of a building

The project natural gas installations will be divided by the stud, from the primary regulators that will be located on the first floor. The secondary regulators that will feed the individual lines in every apartment will be connected from the studs.

RESULTS AND DISCUSSION

The Lean Construction philosophy will be applied in the project of gas installations. Consequently, the project will be classified first to present the measurements of the project, the master planning, and develop a constraint analysis that will result in the released programming.

1. Education and training: the subcontractor's stakeholders, such as the coordinator and foremen, were educated and trained in LPS concepts, tools, and techniques. They were instructed in the dynamics of collaborative meetings that would be implemented from the start of the work. Its objective is to reduce waste in the construction processes.
2. Master Planning: the general contractor has extensive experience in this type of projects, so phase milestones and deadlines are precisely defined. The construction of every building lasts 7 months. The subcontractor became aware of this information and planned the following activities to complete them within the defined deadlines:

- Foundation slab: (a) Layout for ground gas network; (b) Excavation of trenches for network; (c) Placement of gas installations on the slab.
- Structure: (a) Layout of gas network; (b) Placement of valves and gas installations in walls and slabs.

- Finishes: (a) Placement of valves and accessories in the finishes; (b) Placement of protection against impacts and dirt.
- Common Areas: (a) Placement of risers, pipelines, regulatory cabinets and gas meters; (b) Execution of quality tests.

3. Pull Planning Phase Session: the subcontractor participated in the collaborative meetings where they agreed on the Takt Time Planning and the general sectorization of the phase shown in figure 3. The BIM model was used on every level of the gas installations, improving the understanding and analysis of the resources to be used.

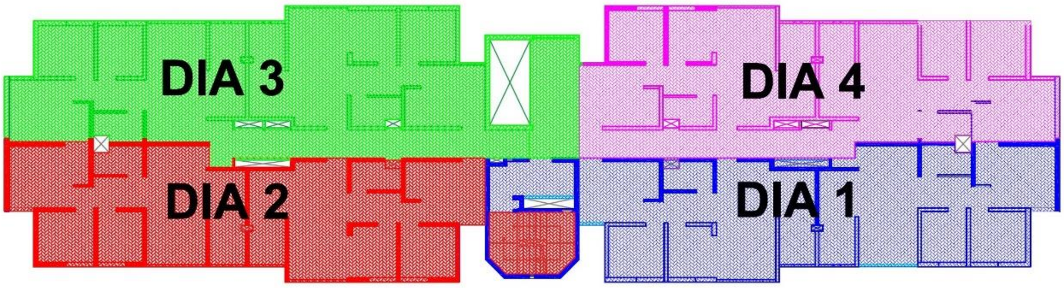

Figure 3: General sectorization of the phase

4. Lookahead Planning and Constraint Analysis: every week, the subcontractor schedules the activities for the next four weeks. The BIM model of every sector is analyzed on a daily basis (see figure 4) and the resources and quality tests of the activities to be conducted are determined. Figure 5 shows the pressure test. For every task, it is determined the constraints of materials, equipment, labor, safety and health, information, previous activities, design, environment, suppliers, subcontractors, among others.

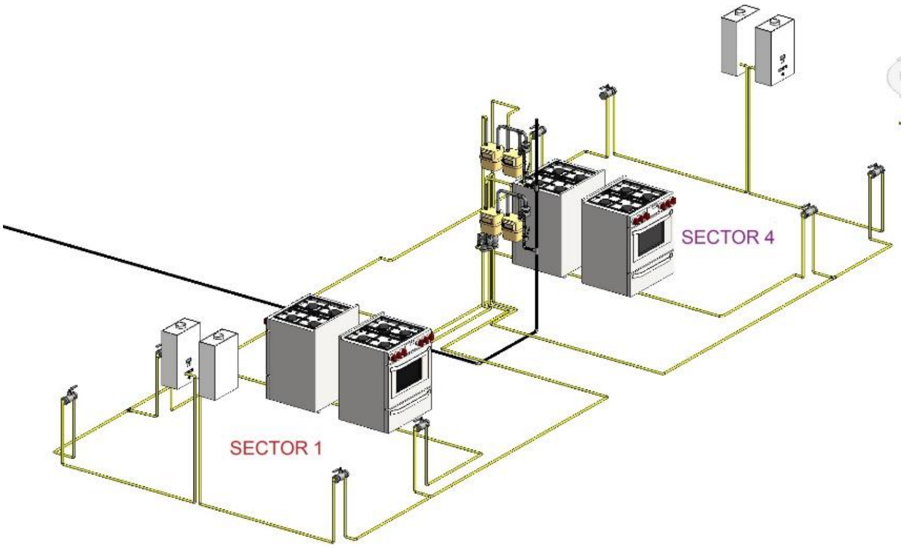

Figure 4: BIM model of every sector

Figure 5: Pressure test

5. Weekly Work Planning and Daily Programming: the subcontractor defined all the tasks that are ready to be executed in the week. Figure 6 shows the takt-time schedule (four sectors, S1 = Sector 1). BIM models are used, daily classifications are approved, and the resources corresponding to every day of the week are analysed.

TASKS/DAYS	1	2	3	4	5
Vertical Rebar	S1	S2	S3	S4	
Vertical Piping Installation	S1	S2	S3	S4	
Vertical Electrical Installation	S1	S2	S3	S4	
Vertical Natural Gas Installation	S1	S2	S3	S4	
Vertical Formwork		S1	S2	S3	S4
Horizontal Formwork		S1	S2	S3	S4
Horizontal Rebar		S1	S2	S3	S4
Horizonal Piping Installation		S1	S2	S3	S4
Horizontal Electrical Installation		S1	S2	S3	S4
Horizontal Natural Gas Installation		S1	S2	S3	S4
Vertical and Horizontal Concrete Pouring		S1	S2	S3	S4

Figure 6: Takt-time schedule of structural work

Throughout all the processes, collaboration was received from the following stakeholders: construction supervisor, subcontractor coordinator, two foremen, and several operators. Among the most remarkable contributions, we can say: (1) The supervisor observes the drawings since the distances to the electrical points and hot water pipelines cause rework, and this situation originates gas installations shutdown; (2) Previous activities cause delays in several stages since drawings are not updated; (3) The natural gas subcontractor assures that the best system is updating the information on the drawings regarding the changes that could occur on site. This facilitates the work on the required items of gas installations. However, there are several companies that do not meet these updates; (4) The poor communication between the parties involves causes many losses, damages, and defects in the items; (5) Operator 1 observes that, in the structure and finishing stages, there are delays due to rework. This situation is due to the lack of knowledge of the regulations of gas installations; (6) Operator 2 indicates that, in the finishing phase, accessories must be secured with masking tape for better protection; (7) Operator 3 observes that for the best operation of installations network, pressure tests must be conducted: (a) during the structures phase, and (b) at the end of the finishing phase during the installation of valves and risers. After that, the root causes of non-compliances are analysed, corrective measures are adopted, and their effectiveness is monitored. For example, all gas installations must have their respective identification from the manufacturer, to avoid the misuse of other brands of accessories and the incompatibility of materials.

Finally, the weekly and accumulated PPC are measured, and their positive performance is verified. Table 1 shows the results of the following 9 weeks. It is observed that in week 2 there were 2 non-compliances, due to lack of materials and lack of quality tests. Corrective measures were immediately adopted, and a person was assigned for every measure to implement it. The routine was then repeated every week, promoting continuous improvement. This methodology leads to efficiency and very high accumulated PPC values, with 96% on average.

Table 1: Weekly and accumulated PPC

WEEK	SCHEDULED TASKS	COMPLETED TASKS	WEEKLY PPC	ACCUMULATED PPC	GOAL
1	10	10	100.00%	100.00%	85.00%
2	10	10	100.00%	100.00%	85.00%
3	10	8	80.00%	93.33%	85.00%
4	17	16	94.12%	93.62%	85.00%
5	24	24	100.00%	95.77%	85.00%
6	26	26	100.00%	96.91%	85.00%
7	27	27	100.00%	97.58%	85.00%
8	33	32	96.97%	97.45%	85.00%
9	34	31	91.18%	96.34%	85.00%

The integration of the Last Planner System (LPS) with Building Information Modeling (BIM) has significantly advanced subcontractor management in our case study project. Key improvements include:

- Enhanced Planning Accuracy: The use of BIM in conjunction with LPS allowed for more accurate and detailed planning schedules. For instance, the visualization capabilities of BIM helped in identifying potential scheduling conflicts early, which LPS methods then addressed through proactive adjustments. This integration led to a marked increase in Percent Plan Complete (PPC) values, from an average of 70% before implementation to 96% post-implementation.
- Improved Resource Allocation: By leveraging detailed BIM models at various planning stages, subcontractors could better predict and allocate resources. This was particularly evident in the weekly and daily planning phases where BIM’s detailed visualizations complemented LPS's structured scheduling approach.
- Increased Subcontractor Collaboration: LPS’s emphasis on regular and structured communications among all project stakeholders was enhanced by shared BIM models. This facilitated a more collaborative environment and improved the subcontractors' commitment to the project timelines and quality standards.
- Feedback and Continuous Improvement: The integration provided a feedback loop where BIM visualizations helped identify non-conformances quickly, and LPS protocols were used to implement corrective actions swiftly. This continuous improvement cycle significantly reduced rework and increased operational efficiency on site.

CONCLUSIONS

The integration of LPS and BIM allows more detailed processes and a better understanding of the natural gas project. BIM and LPS are synergetic, when they interact understanding is improved, decision-making is automated, and transparency is increased. Gas installation subcontractors could generate lower losses using LPS, since it allows better planning and scheduling of the different items identified. It is important that all parties involved are educated and trained in LPS and know the scope of the project. When the implementation of the planning is conducted from the master plan, it is necessary that all collaborators participate in the agreement from the beginning. It is essential to take the respective safety measures to create an environment of confidence to work safely. The most frequent root causes of non-conformances were determined, and this information was fed back into the collaborative planning of the following, determining the optimal classification, Takt Time Planning, subcontractor restrictions, weekly and daily schedules, and finally, the lessons learned from the implementation of the LPS for future projects, which can be adapted to other types of subcontracts.

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