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Planificación colaborativa de subcontratistas usando el Last Planner System: estudio de caso de un subcontratista de instalaciones de gas en proyectos repetitivos de viviendas.
Collaborative planning of subcontractors using the Last Planner System: a case study on a gas subcontractor in repetitive housing projects.

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Resumen-- **La gestión eficiente de los subcontratistas es un desafío en contratos con precios fijos y plazos muy cortos. Son usuales las no conformidades debidas a la falta de calidad de los entregables generándose atrasos y sobrecostos para todos los involucrados, en especial, para el contratista principal. Por otro lado, en los últimos años han surgido sistemas colaborativos como el Last Planner System (LPS), el cual ha demostrado ser muy eficiente en la generación de valor y optimización de los recursos. Sin embargo, existe aún poca información sobre resultados exitosos en la gestión de los subcontratistas. El objetivo principal de este estudio es proponer un método que adapte el LPS en la gestión del subcontrato de instalaciones de gas natural en proyectos de viviendas altamente repetitivos, así como aplicarlo exitosamente. La metodología se aplicó a un proyecto masivo de viviendas económicas multifamiliares en la ciudad de Lima, Perú, el cual se modeló con tecnología BIM. Se determinaron las causas raíz más frecuentes de no conformidades en los primeros edificios, y esta información fue retroalimentada en la planificación colaborativa de los siguientes, determinándose la sectorización óptima, el Takt Time Planning, las restricciones del subcontratista, las planificaciones semanales y diarias, y, finalmente, las lecciones aprendidas de la implementación del LPS para futuros proyectos, los cuales se pueden adaptar a otros tipos de subcontratos.**

Palabras clave— Last Planner System; gestión del subcontratista; gestión de instalaciones de gas; mejora continua.

Abstract— **The efficient management of subcontractors turns into a challenge in contracts with fixed prices and short terms. Non-conformances due to poor deliverables are common, generating delays and cost overruns for all parties involved, especially for the main contractor. In addition, in recent years some collaborative systems have appeared, such as the Last Planner System (LPS), which has proven to be very efficient in the generation of value and the optimization of resources. However, there is still little information about successful results in the management of subcontractors. The main objective of this study is to propose a method that adapts the LPS for the management of the subcontract of natural gas facilities in highly repetitive housing projects, as well as to apply it successfully. The methodology was applied to a massive multi-family low-cost housing project in the city of Lima, Peru, which was modeled by using BIM technology. The most frequent root causes of non-conformances were determined for the first buildings, and this information was used for the collaborative planning of the following buildings. This allowed to determine the optimal sectioning, Takt Time Planning, subcontractor restrictions, weekly and daily planning, and finally, the lessons learned from the implementation of the LPS for future projects, which can be adapted to other types of subcontracts.**

Index Terms— Last Planner System; subcontractor management; gas facilities management; continuous improvement.

I. Introduction

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 analyse the relationship of subcontractors and contractors to improve their performance (Ribeiro et al., 2017). The most frequently used system to implement the Lean philosophy in project works is the Last Planner System (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). However, 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). 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 highly repetitive housing projects.

A. Last planner system (LSP)

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 analysed, 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:

1. Master Planning: the general schedule is developed, deadlines and milestones are agreed, and construction processes are defined (Ballard, 2000).
2. 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 y Brioso, 2016).
3. Lookahead Planning: it is planned by time windows that usually have some weeks according to their variability (Ballard, 2000).
4. 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 (Brioso, 2011).
5. Weekly Work Planning: compliance with the first week of the Lookahead is optimized and buffers are used according to variability and complexity (Ballard, 2000).
6. Daily Programming: the maximum scheduling level is reached, and the use of common equipment is agreed with subcontractors (Brioso, 2011).
7. 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)

B. Subcontractors' management

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 remodelling 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.

C. Building Information Modelling (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). BIM integrates the 3D model of a project with geometric and/or parametric information and is defined as the shared digital representation of the physical and functional characteristics of any object (Sacks et al., 2018). BIM describes the tools, processes, and technologies that create digital

documentation for rates, planning, construction, and operation of a building, reasoning, discussion of ideas, decision making, among other communication factors (International Standards Office, 2018). 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). BIM is synergetic with the LPS (Sacks et al. 2010).

II. 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. Fig. 1 shows the methodology of investigation. The steps are the following:

1. (1) Education and training: subcontractor personnel are educated and trained in the LPS concepts, tools, techniques, and applications.
2. (2) Master Planning: subcontractor becomes aware of the milestones of every phase and organizes its resources to complete them within the specified deadlines.
3. Pull Planning Phase Session: the subcontractor participates in the collaborative meetings. The Takt Time Planning of every phase is defined. The BIM model of the gas installations is developed per level for a better understanding and analysis.
4. Lookahead Planning and Constraint Analysis: every week, the subcontractor schedules the activities for the next four weeks. The BIM model of every daily sector is prepared and the requirements of the activities to be conducted in the following four weeks are defined, with focus on compliance of the first week.
5. Weekly Work Planning and Daily Programming: the subcontractor defines all the tasks that are ready to be executed in the week. BIM models are used, daily sectorizations are approved, and the resources allocated to every day of the week are analysed.

Fig. 1. Research methodology.

6. Learning (Reliability Analysis): the root causes of non-compliance are analysed, corrective measures are adopted, and their effectiveness is monitored.

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 modelled with BIM

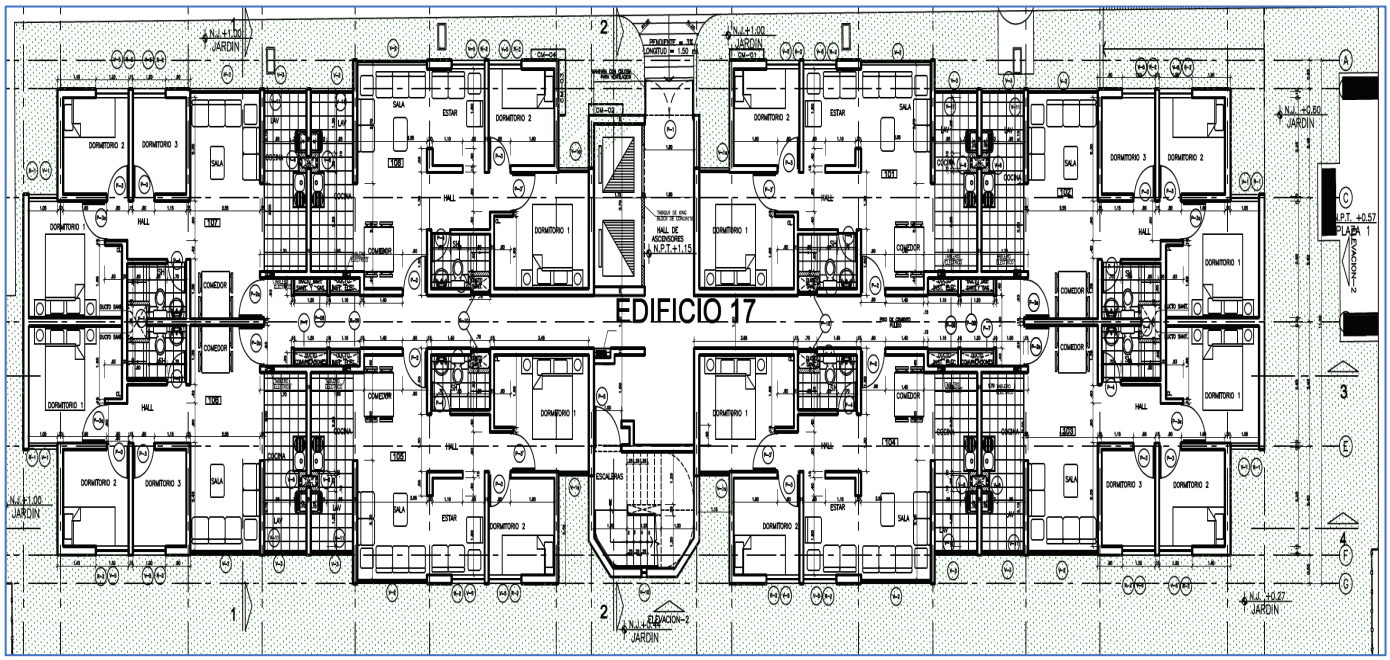

Fig. 2. Typical floor plan of a building.

technology, Revit 2021 software. The project is in the city of Lima, Peru, with a built area of 7,372 92 m^2. It consists of 4 housing buildings with 16 floors, 512 apartments of 49.50 m^2 and 50.40 m^2 of covered area. The structure of every building is made of reinforced concrete and has low-cost finishes and installations. Fig. 2 shows the 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. Fig. 3 shows the typical distribution of natural gas of a building modelled BIM.

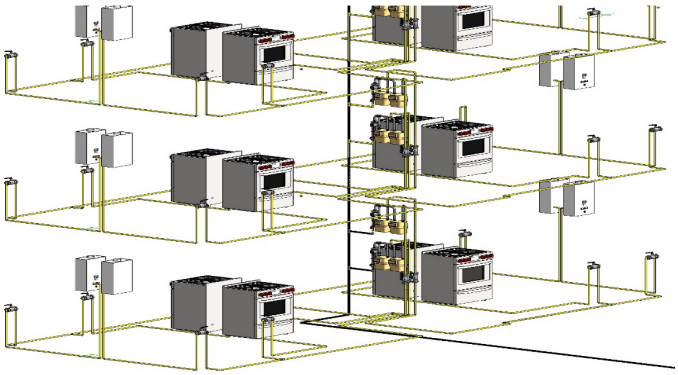

Fig. 3. Distribution of natural gas installations

III. Results

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.

- 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.
- 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.
- 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 4. The BIM model was used on every level of the gas installations, improving the understanding and analysis of the resources to be used.
- 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 daily and the resources and quality tests of the activities to be conducted are determined. Figure 6 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.
- Weekly Work Planning and Daily Programming: the subcontractor defined all the tasks that are ready to be executed in the week. Figure 7 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.
- Learning (Reliability Analysis): the root causes of non-compliance are defined, such as lack of planning, scheduling changes, fatigue due to overtime, lack or failure of equipment, lack of materials, inadequate work method, unfinished previous activities.

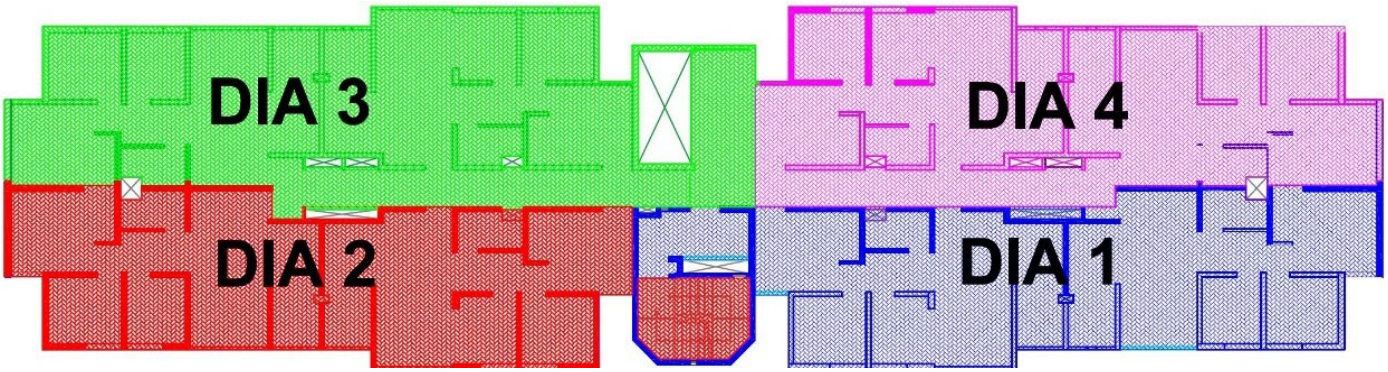

Fig. 4. General sectorization of the phase.

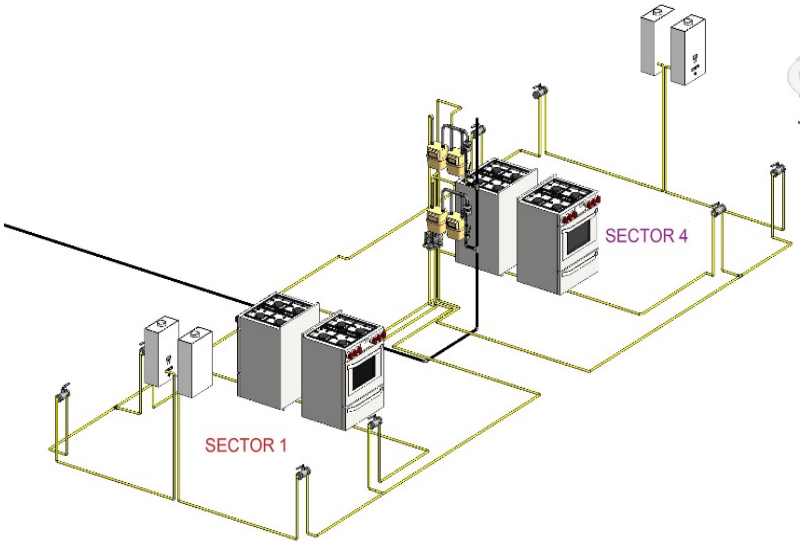

Fig. 5. General sectorization of the phase.

Fig. 6. General sectorization of the phase.

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.

Finally, the root causes of non-compliances are analysed, corrective measures are adopted, and their effectiveness is monitored. The weekly and accumulated PPC are measured, and their positive performance is verified. Table 1 shows the results of the first 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.

TABLA I
SFD´LKVHR´LKDHFVÁDLKFHVZDLKFHVAD

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

TABLA II
WEEKLY AND ACCUMULATED PPC

WEEK	SCHEDULED TASKS	COMPL. TASKS	WEEKLY PPC	ACCUM. 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%

IV. 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 are 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.

• 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.

• 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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