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# PREFABRICATED REINFORCEMENT IN CONSTRUCTION USING VDC: CASE STUDY OVALO MONITOR BRIDGE

Tesis para optar el Título Profesional de Ingeniero Civil

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# PREFABRICATED REINFORCEMENT IN CONSTRUCTION USING VDC: CASE STUDY OVALO MONITOR BRIDGE

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## ABSTRACT

In construction projects, there may be rework and delays associated with construction processes with a low level of industrialization, resulting from the lack of constructability of the designs. To promote industrialization and improve the project's constructability, we implemented the Virtual Design & Construction (VDC) methodology, combined with a system of prefabricated reinforcement cages (PRC) elements in constructing an 870-meter span bridge located in Lima, Peru. The objective was to reduce structural rebars' assembly times, replace the traditional on-site processes of cutting, bending, and assembling steel with an industrial process based on systems of PRC steel elements. As a result, the assembly times of the structural item were reduced by 31%, thanks to the use of PRC elements. In addition, due to the VDC methodology, a 100% buildable design of the PRC elements was achieved.

## KEYWORDS

VDC, BIM, bridges, industrialized construction, prefabricated reinforcement.

## INTRODUCTION

Traditional construction systems can imply unnecessary expenses and loss of resources, either in labor or in materials and tools, which can affect the quality of the final project (Penadés Martí, 2002). Therefore, humans have always sought to improve and optimize every process they perform, eliminating waste. Construction is one such process, which has been subjected to several changes and revolutions (López Flores, 2018).

In recent decades, there has been a growing interest in advances in industrial construction. As Qi et al. (2021) explain, industrialized construction integrates design and optimization tools to solve complex challenges in construction projects. The most discussed benefits of industrialized construction are cost reductions, productivity improvement, and the reduction and optimization of construction times.

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The prefabricated reinforcement cages (PRC) for reinforced concrete elements are essential for precast concrete and, therefore, for the construction industry. According to Simonsson and Emborg (2007), approximately 50% of the total construction cost of a bridge infrastructure comes from reinforcing steel and pouring concrete *in situ* and comments that from an ideal theoretical point of view, the time reduction on-site can reach up to 80% savings. This means that implementing construction methods that reduce time and costs is essential to maximizing the project's profit. PRC can reduce construction costs and time while improving fabrication quality and safety (Devine et al., 2018).

According to Acevedo Díaz (2009), in traditional construction work, the cutting, bending, assembly, and installation of rebar is done manually, with these tasks being carried out by the construction workforce. So, as on-site steelmaking is a craft job, removing these activities from the main production line (construction site) helps mitigate potential accidents and decreases the workload of the general contractor, allowing greater focus on other areas of construction.

The alternative of preassembling the steel bars in a workshop allows for overlapping activities and saves time in the construction. By migrating these activities to the support production lines, the time used to execute the jobs will not be greater than in systems that do not use preassembled rebar cages (Espinoza Conislla, 2012, p. 83).

Another significant aspect of the construction industry is project management - more collaborative and inclusive management where all actors collaborate towards a common goal. Collaborative management is crucial to reduce costs and avoid schedule delays because it involves all stakeholders, reducing risks and increasing efficiency in decision-making (Kunz, & Fischer, 2020). One of the methodologies that promote collaborative management is the Virtual Design & Construction (VDC) methodology.

VDC is known as the use of models under multidisciplinary performance in a different design - construction projects, work process flows, and the organization of the design - construction - operation team, including the product, to achieve business objectives (Kunz & Fischer, 2020). The VDC methodology is presented through a VDC framework with its three components: ICE (Integrated Concurrent Engineering), BIM (Building Information Modeling), and PPM (Project Production Management).

We present the Virtual Design and Construction (VDC) methodology as a point of interest to the AEC industry. From the literature review, few research papers discuss the time benefits of implementing the VDC Framework with a pre-assembled industrialized process. These help to optimize construction processes through the standardization of pre-construction of structural elements and the collaborative management of the project (Corrales Tamayo and Saravia Torres-Llosa, 2020).

Motivated by those above, we present how PRC elements and the VDC methodology benefit the construction of an 870-meter span bridge located in Lima, Peru.

## DEVELOPMENT

Industrialized construction, also called construction 4.0, refers to adopting technologies and digital tools to optimize construction processes. This industrialization implies that the infrastructures to be built are processed as manufacturing processes rather than as independent projects (Villena Manzanares et al., 2020, p. 425). This means that it is made more efficiently, reducing on-site construction work.

For Xue et al. (2018), the construction sector is one of the industries known for its scarcity of innovation. This is due to the unique nature of projects relying purely on on-site productions, various stakeholders involved, etc., which causes a low integration of the new industrialized construction methodologies (remaining resistant to change from conventional practices), affecting the quality of the final product. In the same way, Qi et al. (2021) mention that industrialized construction also faces specific problems and obstacles, which injure efforts to be fully implemented and subsequently adapted within the construction sector. Despite the benefits that can be obtained, there is still a lack of communication, a lack of quality inspection systems for manufacturing and installation activities, and poor efficiency concerning the supply chain (Qi et al., 2021).

## PREFABRICATED REINFORCEMENT CAGE (PRC) ELEMENTS

The preassembled elements are generally carried out outside the building/site. The final placement is the only on-site task to be carried out (Espinoza Conislla, 2012, p. 75). On the other hand, all the work is done in traditional assembly. A work area must be freed up to cut and bend the steel and then assemble it at its final point, piece by piece. Subsequently, the formwork of the element is completed, and then finally, the concrete is poured. So, outsourcing the cutting and bending of steel allows for increased productivity, quality, and safety, reducing costs, construction time on site, and labor inspection (Devine et al., 2018).

In traditional systems, the steel bars and stirrups will have to be transported individually, probably with the support of cranes. On the other hand, the crane can move the material in a single movement by having the entire element already prefabricated and ready to install (Acevedo Díaz, 2009). This is more efficient and reduces machine usage time per batch.

A substantial benefit of pre-assembly is carrying out different activities simultaneously. In a project with traditional reinforcement, the reinforcement of the beams of a slab cannot begin until the beam bottom formwork is installed (Espinoza Conislla, 2012). On the other hand, it is possible with the assembly in a factory. Allowing formwork and steelwork to be done simultaneously helps eliminate wasted time. The assembly is no longer dependent on the formwork subcontractor. Having the shaft preassembled and available generates a minimum inventory (PRC element available and ready to install) to have a buffer and transport the structural elements from the workshop to the construction site when needed, avoiding wasted time. On the contrary, the inventory could also be held on-site, ready to be installed when available. The drawback is the valuable space it would occupy when it remains as inventory.

Devin et al. (2018) found through a qualitative survey that the work time of the workforce for the mooring of the bars is reduced by 27% when the prefabrication of the elements is carried out. But once the additional time consumed in transporting the preassembled components is considered (transport from the supplier to the factory and then from the factory to the construction site), the total savings are reduced to approximately 1-14%.

Simonsson and Emborg (2007) state that outsourcing the prefabrication of rebar cages is usually connected to using better tools, automated equipment, and skilled labor to operate them, minimizing failures and improving quality. Therefore, industrialization means a more controlled and specialized work system.

Likewise, contracting PRC reduces the variability or uncertainty of the general contractor regarding the items of reinforcing steel since there are fixed delivery dates coordinated with the supplier (Acevedo Díaz, 2009). Whereas with a non-industrialized construction, the assembly of each element would depend not only on the delivery of the material (rebar) by the supplier but also on the contractor in charge of fitting and assembling the element. Furthermore, there is a substantial difference in material loss. The study conducted by Kim et al. (2013) noted an expected loss of steel of 10% in traditional systems. In contrast, this loss estimate drops to just 3% in an industrialized system.

The pre-assembly of rebar cages is a construction process that brings many benefits to the construction project; however, there may be some drawbacks, such as:

- The tower crane must move the steel elements, and, therefore, any other activity that requires the use of the crane must wait its turn (Espinoza Conislla, 2012).
- A possible problem faced by the assembly of construction bars in a factory is the movement of the longitudinal and transverse elements in the transport to the construction site and the subsequent assembly to its final position (Devine et al., 2018). Therefore, the tie given to the bars with the stirrups must be carried out with due care to avoid the bars' final spacing that does not violate any standard or affect the structural stability of the element.
- In the case in which the pre-assembly is carried out on the same land as the building or infrastructure project, space will have to be assigned to carry out this work (this is not a problem if the work is outsourced to a subcontractor with his workshop) (Espinoza Conislla, 2012).
- Another problem that could arise is that the design of the PRC is not compatible with those delivered by the supplier. This is due to issues with blueprint readings and poor communication between stakeholders. Fortunately, this can be identified in advance and avoided through collaborative work management (Acevedo Díaz, 2009).

Maciel and Corrêa (2016) state that deficiencies in steel cutting and bending in pre-assembly factories may be related to poor management, communication, and information exchange between stakeholders, and steel designers, builders, and manufacturers. It is necessary to manage this industrialized construction process in a more collaborative, efficient, and effective way, using Virtual Design & Construction methodologies detailed below.

## VIRTUAL DESIGN & CONSTRUCTION (VDC)

The main components of VDC are the following:

a) Client and Project Objectives

Both the client's and the project's objectives must be aligned to meet the goals. The VDC framework makes teams focus on determining the desired performance of the task and the total cost as a whole. In addition, the project must be considered usable, buildable, operable, and sustainable (Rischmoller et al., 2018).

b) ICE (Integrated Concurrent Engineering)

ICE is derived from the so-called "External Collaboration" methods, an initiative carried out by NASA's Jet Propulsion Laboratory (JPL). For Chachere et al. (2009), ICE works as a methodology that overcomes the traditional isolated way of working. This component applies engineering analysis, along with communication and decision making.

c) BIM (Building Information Modeling)

For Qi et al. (2018), the main essence of BIM is information management and project visualization. This contains certain information in detail and with a higher integration of all the specialties. These details make transparent communication between stakeholders possible. On the other hand, it is stated that the main reason for this information management is to help decision-making by the work team and other stakeholders, which ensures that all project information is always available.

d) PPM (Project Production Management)

There are three general dimensions cataloged as problems within this industry in all construction projects: stakeholders, the organization of the internal activities of the work team, and governance. For this topic, Lean Construction encompasses these three dimensions and is complemented by PPM, whose scope focuses on both the organization and the activities of the project teams. This component focuses on controlling the tasks (to improve time, cost, and quality) or actions of the work in each project and its organization. PPM delves into the achievable limits of the job functions to be carried out and ratified in several possible scenarios. It also optimizes performance, work processes, and capacity through specifically defined parameters to improve costs, time, and the defined scope of the projects (Shenoy, 2017).

e) Metrics

Metrics are based on milestones to give a better and more consistent view of the project. This generates a higher probability that the teams involved will complete the project more efficiently on budget and schedule while maintaining the quality of the work (Majumdar et al., 2022). This must be translated according to the client's and project's objectives for use, functionality, and sustainability in quality, health and safety, cost, and time (Belsvik et al., 2019).

In general, VDC methods demonstrate different benefits, such as better visualizing the project and integrating information to forecast the project's results and manage performance and expected outcomes (Hassan et al., 2018).

# METHODOLOGY

This research is based on a quantitative approach. The literature is reviewed, and a theoretical perspective is built to support the data collected from a case study. From this, the data was evaluated through the production metrics.

## Study Area

Information related to the Ovalo Monitor Bridge project in Lima, Peru, has been compiled to carry out this work. As shown in Figure 1, this work was developed at the intersections of the avenues Palmeras - Javier Prado Este - Golf de Los Incas (Ovalo Monitor) that involve the districts of La Molina and Santiago de Surco, having a projection of about 2 kilometers.


Figure 1: Aerial view of the in-development Ovalo Monitor Bridge project (Google Earth, n.d).

**Stages, processes, techniques, and tools used for the research**

1. In the first stage, a bibliography inquiry was carried out in internet-based sources regarding the keywords relevant to the research topic. These were "VDC," "bridges," "prefabricated reinforcement," and "rebar cages." This search was done primarily in the Scopus and Web of Science databases and other sources such as institutional repositories of universities. Based on this information, the approach to the research problem, justification, and background of the work was developed.
2. Then, in the second stage, we focused on data collected from the Ovalo Monitor Bridge Project in Lima, Peru. This is a project managed with VDC and built with PRC. The level of industrialization (prefabricated reinforcement cage) was monitored between January 2021 and January 2022 (initial coordination of work and pre-design, design, construction, and assembly), as follow:
    - Collection of agreements and observations with the client regarding the prefabricated reinforcement cage and its delivery times.
    - Collection of changes in the design related to the use of reinforcing steel (PRC).
    - Collection of the industrialized parts of the project supported by the BIM model.
    - Collection of the percentage of industrialization concerning the entire project and by structural element.
    - Collection of client's and project's objectives to develop the VDC Framework of the project.
3. In the third stage, this information was used to identify the benefits of industrialization over a traditionally built and managed project through data processing and analysis. The metrics used are described in the next section.
4. In the fourth and last stage, the research work results, discussions, and conclusions are presented.

## RESULTS AND DISCUSSION

The data collection structure consists of monthly data tracking production metrics and controllable factors according to the VDC application for the Ovalo Monitor Bridge project. The following VDC Framework was proposed based on the information collected.

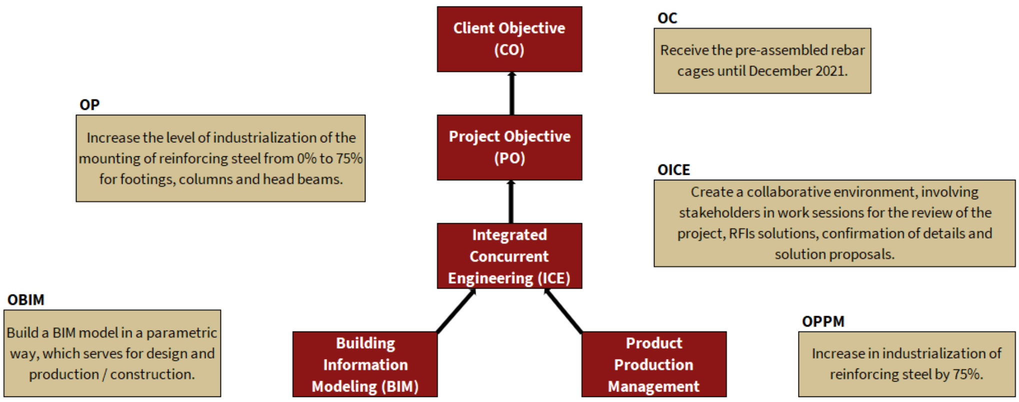


Figure 2: VDC framework proposed for the Ovalo Monitor Vehicular Bridge project.

This framework was developed according to the client's objectives, project, ICE, BIM, and PPM. The project's production metrics and controllable factors were developed in Table 1 to provide an adequate follow-up of the VDC implementation in the design, construction, and assembly of pre-assembled rebar cages (PRC).

Table 1: Production metrics and controllable factors (ICE, BIM, PPM).

| Objective | Metrics | Goal |
|---|---|---|
| PM_ICE: Facilitate and integrate the activities and tasks of the teams involved in charge of the project (delivery of PRC elements). | $\%PPC = \frac{\#\text{Activities completed}}{\#\text{Total activities to be completed}} \times 100$ | 100% |
| CF_ICE: Promote the participation of all teams involved in each ICE session. | % Attendance at each ICE session | 100% |
| | Frequency of ICE sessions | 2 per month |
| PM_BIM: Measure the scope of the BIM model to quantify the elements that will be preassembled. | $\%PM = \frac{\text{PRC to be modeled in BIM}}{\text{Total elements modeled in BIM}} \times 100$ | 100% |
| CF_BIM: Define LOD to be used. | Minimum LOD required | 350 |
| PM_PPM: Reduce the construction time of the structural item by 25%. | % Reduction Time | ≥ 25% |
| PM_PPM: Increase the level of industrialization of reinforcing steel assembly in the substructure by 75%. | % of industrialization | ≥ 75% |
| CF_PPM: Follow up on weekly progress. | # Weekly progress monitoring review days | 1 per week |

%PPC: Percent Plan Complete
%PM: Percentage Modeled
LOD: Level of Detail

From ICE, we registered the comments and the agreements with descriptions of the information related to incompatibility, conflict points, and proposals for improvements. To overcome the identified issues, ICE sessions were conducted with the support of a collaborative environment and the assistance of the stakeholders. Figure 3 presents the production metrics and controllable factors from January 2021 to January 2022.

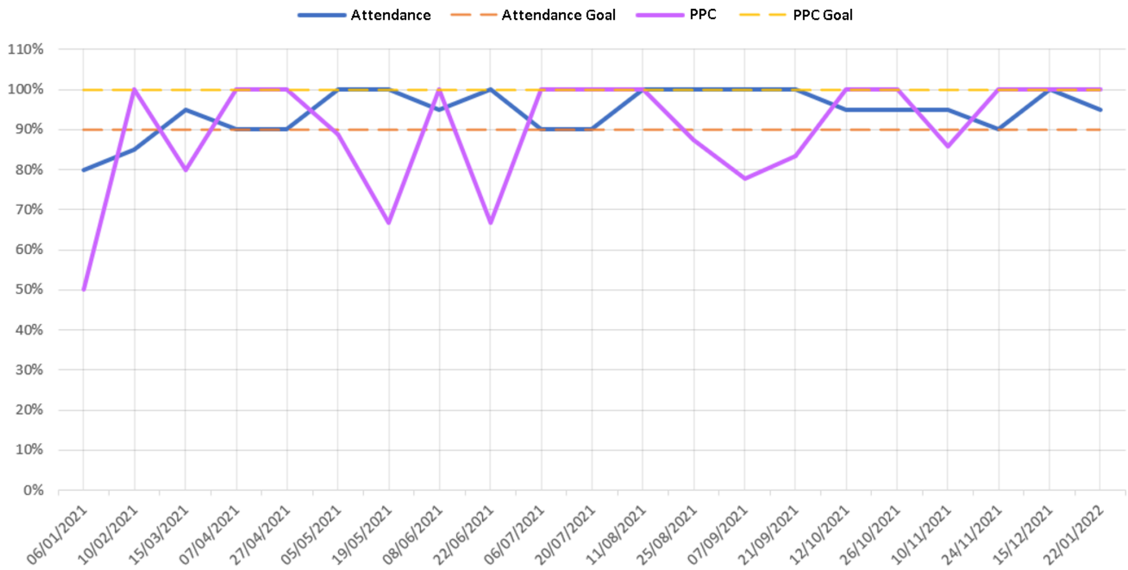

Figure 3: Production metric and controllable factor for ICE: Attendance and %PPC.

Figure 3 shows 80-100% attendance across all ICE sessions held in 2021 and 2022, with an average of 95%. With 72 queries received, 100% of them have been resolved. These queries discussed in ICE sessions were noted and monitored, classifying them by the type of change required by the project. This list of observations was directly related to the ICE metrics and controllable factors identified in Table 1. There was a focus on the resolution of comments and on reducing the response time of those decisions.

Concerning the BIM component, in Figure 4, all PRC proposed elements were modeled with a minimum LOD 350. The modeling of each section of the structural item of the Ovalo Monitor Bridge was obtained, and the LOD 350 and 400 were developed as follows. For Section 1, the modeled time was from April 19th to September 6th, 2021. For Section 2, from July 5th to November 22nd, 2021. For Section 3, from July 12th to November 29th, 2021. For Section 4, from August 8th to December 22nd, 2021.

Each section consists of a partial milestone in the bridge's 870-meter length (going from west to east). A breakdown for each structural element preassembled was 100% available for all stakeholders to visualize and understand each element.

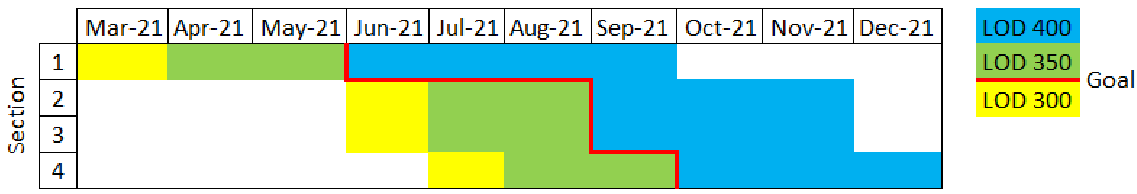

Figure 4: Controllable factor for BIM: BIM model progress based on LOD requirements.

The Level of Detail refers to the level of detail that a BIM model needs depending on the focus of the work. The LOD 350 required as a minimum refers to a level of detail of the precise BIM model that must be used to carry out the PRC (Hinostroza Quilli & Romero Falcon, 2019). This is to compatibilized the information of the blueprints that were made in the BIM models.

Figure 5 shows that the time saved in the structural item by using PRC elements and implementing a VDC framework was 31%. This was thanks to the appropriate use of the tools provided by each VDC component. The BIM models helped to visualize better the PRC elements that would be pre-assembled. The ICE sessions promoted collaborative meetings to carry out the necessary consultations among the stakeholders and to be able to resolve these consultations in less time, which helped to make better decisions in less time. PPM provided an improvement in terms of detailed tracking of the progress of PRC elements to know their status for each week of progress (Look Ahead).

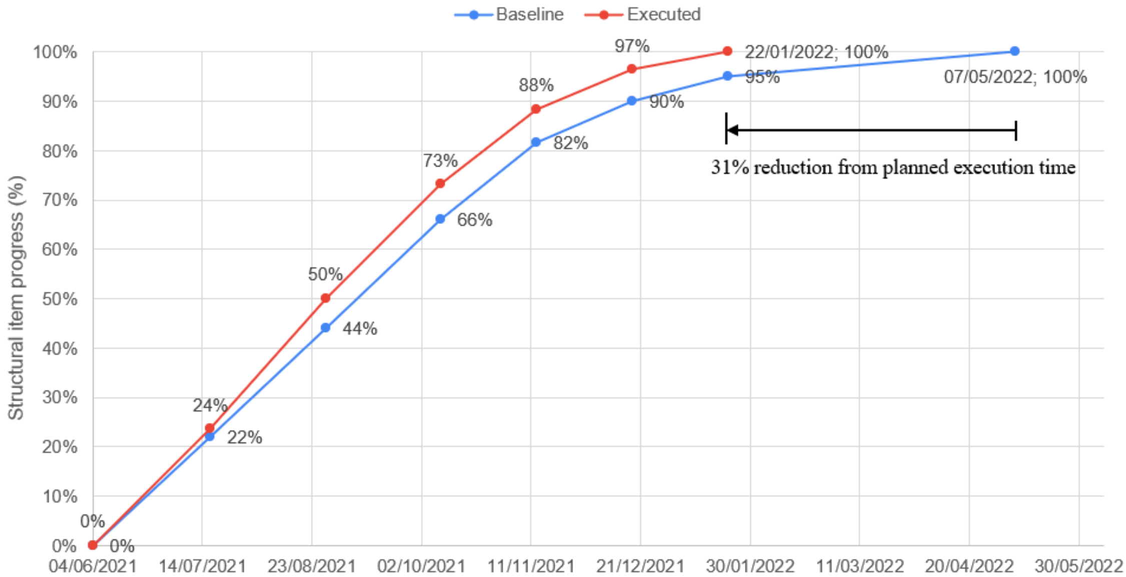


Figure 5: Production metric for PPM: Reduction Time (%) in structural item supported in PRC elements.

Figure 6 shows the percentage of industrialization of the preassembled elements for each type of structure (substructure and superstructure) over time for the PPM component. 85% was reached for the substructure, exceeding the industrialization goal for the elements that compromise this structure: footing, column, and header beam. Also, it is possible to visualize how this percentage has increased over time, which has helped reduce the assembly of these elements in the field.

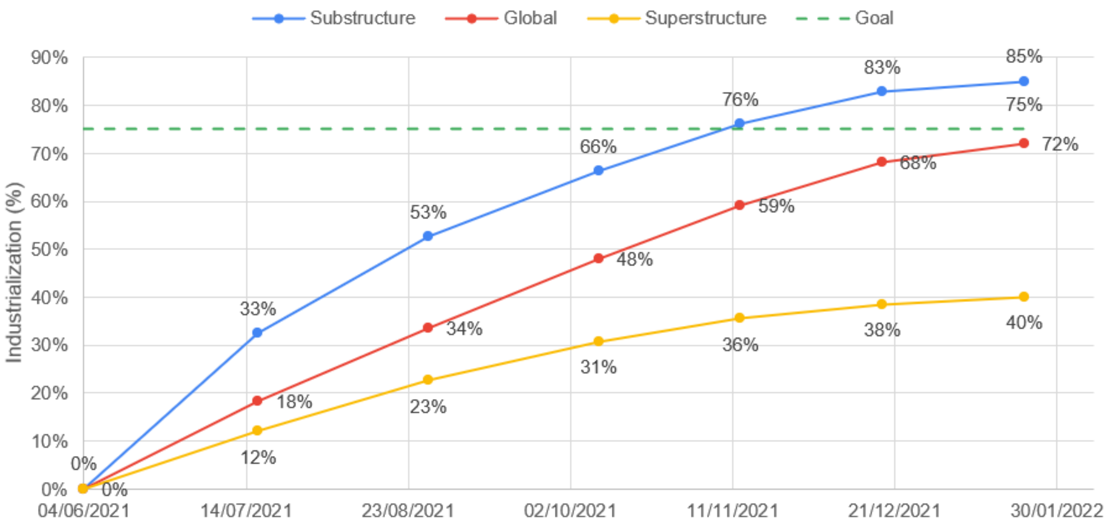


Figure 6: Production metric for PPM: Industrialization (%) based on steel weight (ton).

A 75% industrialization target was defined as an action to reduce project execution time. This percentage is measured according to the weight (ton) of the PRC elements that will be pre-assembled concerning the total reinforcing steel intended to be used.

According to Porras et al. (2014), Lean Construction is considered a philosophy oriented to production management in the construction sector. Its primary objective is to reduce or eliminate tasks or activities that do not add value to the project. In this way, PPM helps meet the Lean objectives of focusing on ridding activities or processes that do not generate value for the project. Table 2 shows a follow-up of the overall progress of the PRC-related activities to the Ovalo Monitor Bridge project, which allowed the value-adding and waste-reduction monitoring of the project to take place. The goal was to do a weekly follow-up throughout 2021 and the beginning of 2022. Only six weeks were missed in the entire period.

Table 2: The controllable factor for PPM: Follow up on weekly progress.

| W/M | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ |
| 2 | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ |
| 3 | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 4 | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 5 | | | ✓ | | | ✓ | | | ✓ | | | ✓ | |

W: Week (rows)
M: Month, from January 2021 to January 2022 (columns)

# CONCLUSIONS

The results discussed in this research showed that the VDC methodology, in conjunction with the industrialization of the structural construction process, brings time-saving benefits to a construction project, as was the case study: the Ovalo Monitor Bridge in Lima, Peru. The time saved concerning the assembly and installation of prefabricated reinforcement cage elements was 31%, close to the 27% found by Devine et al. (2018).

The industrialization percentage of 85% for the superstructure (footing, column, header beam) was measured up to January 2022, overcoming the 75% target defined in the project's objective. This was due to the involvement of the leading stakeholders in the ICE sessions to propose constructability improvements and resolve observations regarding the detail of the PRC elements.

With BIM integrated into the VDC framework, the prefabricated reinforcement cage elements were ordered with exact measurements, eliminating any issue related to change orders. In addition, all elements were prefabricated from the information provided by the BIM model, with zero rework. This also helped the stakeholders better understand what was to be prefabricated and assembled on site.

PPM provided weekly monitoring of the progress of the PRC elements deliveries, which allowed to improve this process and make better decisions as the project progressed.

Finally, implementing collaborative management and industrialized construction methods can minimize rework and reduce time compared to traditional approaches.

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