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OPTIMIZATION OF DESIGN COORDINATION PROCESSES FOR A 7-STORY MULTIFAMILY BUILDING USING VIRTUAL DESIGN AND CONSTRUCTION (VDC)

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OPTIMIZATION OF DESIGN COORDINATION PROCESSES FOR A 7-STORY MULTIFAMILY BUILDING USING VIRTUAL DESIGN AND CONSTRUCTION (VDC)

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ABSTRACT

Traditional construction and property companies often find themselves bound by conventional project management and design techniques, which can lead to delays during the design phase. This situation needs to be avoided. This study presents a process optimization for the design stage of multifamily buildings using Virtual Design Construction (VDC) - a collaborative project management approach. Focused on a case study involving two residential buildings developed by the same property company in Lima, Peru, this research commences with a comprehensive analysis of the existing design processes from the projects. By pinpointing key sources of variability and streamlining the design flow, the proposed VDC implementation aims to enhance compliance with project timelines and the approval of design drawings. The optimized process yielded tangible results, significantly reducing design time, completing tasks ahead of the scheduled deadline, and improving the delivery of technical files by 25%. These outcomes underscore the benefits of this optimized process, including enhanced project efficiency and improved design quality, thereby making a compelling case for applying VDC in similar construction projects by property companies.

KEYWORDS

VDC, BIM, collaboration, concurrent engineering, process optimization.

INTRODUCTION

The construction industry, a dynamic field where professionals always look for innovative tools and methodologies to streamline and automate processes (Hermida, 2022), has witnessed the emergence of a potential game-changer, Virtual Design and Construction (VDC). This approach, which involves a shift from traditional 2D drawings to a comprehensive 3D model that integrates all project information (Del Savio, 2018), holds the promise of revolutionizing the industry. The transformative potential of VDC becomes evident when an integrated team collaborates in creating and managing information and decision-making using this approach.

Despite the constant evolution of new technologies, traditional property companies have not fully adopted these changes (Cantó, 2017). Various challenges in the development of residential

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building projects include, in addition to productivity issues, low design quality, inconsistent drawing production (Alvarez et al., 2021), incompatibilities between specialties (Bravo & Ramirez, 2019), lack of clarity in information (Almonacid et al., 2015), delays and cost overruns (Figueroa et al., 2021).

One key factor contributing to these issues is the deficient stakeholder communication during the design stage. The lack of efficient communication leads to delays as team members focus on individual objectives rather than project ones (Del Savio et al., 2022). Incompatibilities and team fragmentation hinder the maximization of project performance (Ma et al., 2018).

This study explores a collaborative management method to address previously discussed issues, focusing on the VDC methodology. VDC is a project management framework developed at the Centre for Integrated Facility Engineering (CIFE) at Stanford University, aiming to enhance the design, construction, and operation of projects via Building Information Modeling (BIM), Integrated Concurrent Engineering (ICE) and Project Production Management (PPM) (Del Savio et al., 2022). From a design perspective, VDC provides an integrated objective among the team, guiding them to the client's specific needs and generating production metrics to measure the results of the processes (Majumdar et al., 2022a). This involves delivering the project design on the agreed-upon date using BIM, ICE, and PPM (Majumdar et al., 2022b).

Motivated by the challenges presented within the construction sector, this work investigates the effect of implementing VDC to enhance stakeholder communication during the design coordination stage, aiming to reduce the overall time spent in this phase. The general objective of this research is to optimize the processes of the design stage for a residential building using VDC as a collaborative project management methodology. It involves analyzing the existing processes of the property company, identifying key sources of variability, and focusing on a more coordinated design flow to ensure compliance with delivery time and approval of the design drawings of the project.

This investigation starts by describing the methodology and the case study. Then, it analyzes the existing literature on VDC. Next, it explains the proposal for implementing VDC and its application in optimizing the design coordination processes in the case study. The results obtained from the VDC-based process were compared against the traditional process used in the former project of the property company under study. Finally, discussions and conclusions showed how VDC can enhance the design coordination process.

LITERATURE REVIEW

Fosse, Ballard, and Fischer (2017) investigated the benefits of utilizing collaborative work methods with digital tools and explored the factors driving this work and its limitations. The benefits of VDC implementation were measured using quantifiable metrics.

Kunz and Fischer (2020) examined the adoption of VDC in the construction industry and analyzed its economic impact. The study measured the benefits of using the VDC framework in the construction industry and assessed the global growth of VDC adoption.

Del Savio et al. (2022) provided an updated approach to the VDC methodology, offering a comprehensive review of current tools and methodologies. The approach is supported by its benefits related to client and project objectives, specifically regarding project costs and timelines. Implement VDC in a project starts from the client's objective, which is examined according to the relationship between the product (P), the organization (O), and its processes (P) within the POP matrix to create the foundation from which the VDC framework is developed (Del Savio et al., 2022). Once the framework's objectives are established, each component is studied in detail to develop production objectives, controllable factors, and metrics that enable the project to achieve its goals.

Balcazar et al. (2023) studied the construction process optimization of concrete structural elements using VDC, solving 60 possible clashes before construction. Quinteros Perez et al. (2023) studied the optimization of time in the processes of plumbing systems with VDC, reducing design time by 5% and execution time by 23%. Salazar et al. (2023) studied time optimization in diamond drilling operations in mining projects using VDC, resulting in a time optimization in operations of 10%. Barcena et al. (2023) studied optimizing the construction process time of a reinforced concrete reaction slab using VDC, resulting in a time reduction of 44 days. Palpan et al. (2022) studied a project's time reduction with an industrial process managed with BIM, resulting in a time reduction of 16%. Tuesta et al. (2022) studied the reduction of structural rebars' assembly time using VDC, resulting in a time reduction of 31%. Bustamante et al. (2023) proposed a VDC framework for curtain wall construction process optimization.

RESEARCH METHODOLOGY

This research is exploratory (Morales, 2015), analyzing the benefits of implementing a collaborative management methodology in the design stage of a residential building developed by a property company. The goal is to reduce variability and delays by identifying key optimization factors in the traditional workflow. This experimental research is quantitative (Babativa, 2017) and involves the implementation of the VDC methodology in a building project. The impact was measured through data collected using performance metrics. See Figure 1 to follow the research methodology.

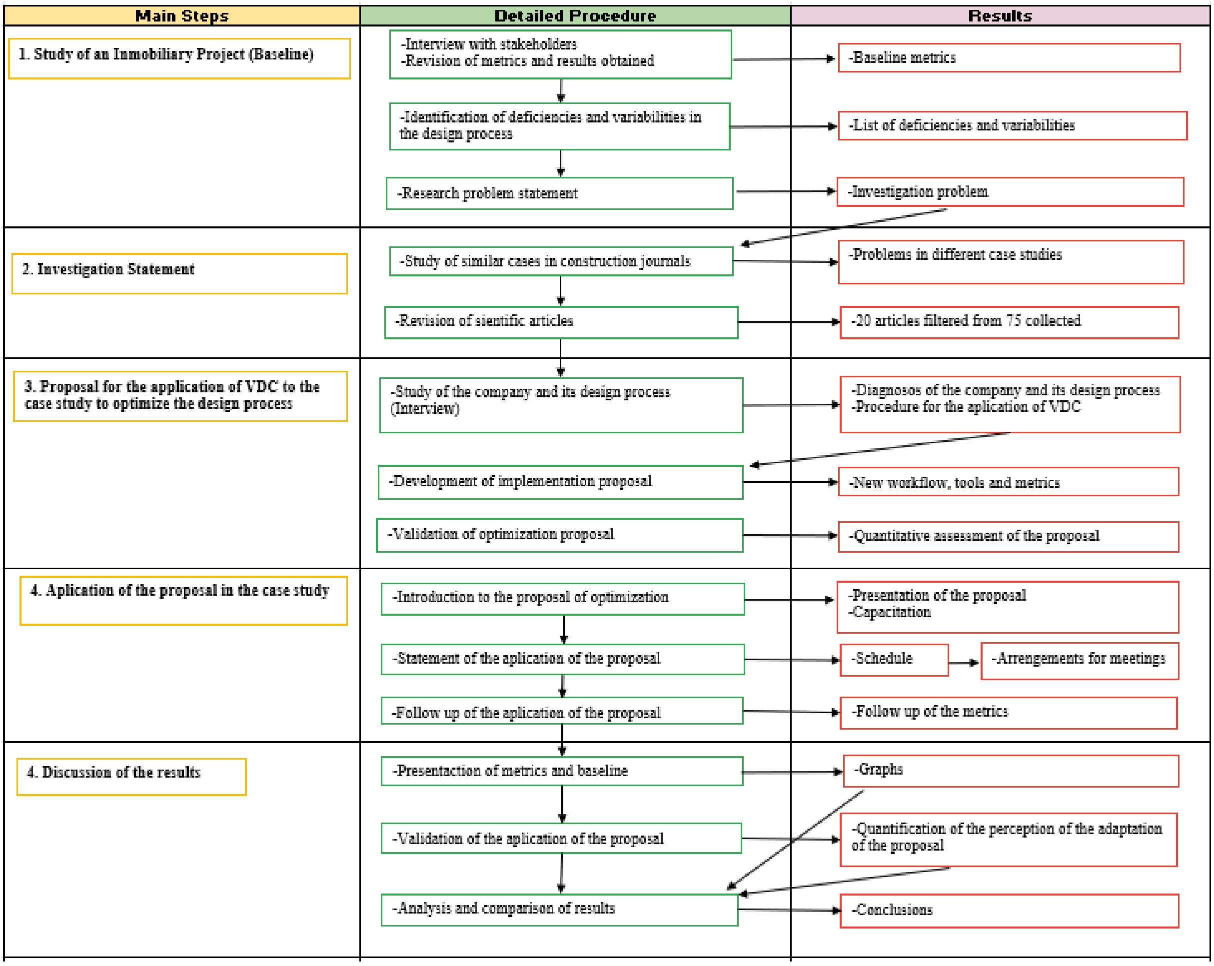

Figure 1: Research Framework.

To formulate the research problem, an in-depth examination of a building project in the design phase was conducted. Interviews with stakeholders, revision of metrics and results of previous projects, and identifying deficiencies and variabilities in the design process were carried out. The case study was initiated to test the hypothesis about a new company project. The development of a new workflow for project design began with interviews with the designers and project management teams to diagnose the current work methodology of the company.

For the optimization proposal, an interview with the construction manager, a Civil Engineer with more than 10 years of experience in building projects, provided insights into the company and its design process. A literature review of the VDC methodology applicable to the design process was conducted. Combining this review with interview data, an optimization proposal for the design process was crafted. The proposal started by elaborating a POP matrix and a VDC framework. The proposal was presented and then validated through a survey directed at participants in the design phase of the new project.

Following the proposal, a training process for staff and a schedule planning for the design process were executed. The planned changes in the workflow were implemented, and their application was monitored throughout the design stage with recorded metrics defined in the VDC framework. Performance metrics results were compared with those of the previous project to verify if improvements in the design process had occurred. The criteria for comparing both projects during their design phase included:

- Difference between approval of the preliminary project design and the delivery of the final technical file of the specialties involved in the design stage.
- Differences in drawing versions of the designers created to deliver the technical file.
- Difference in time between change requests from the company and drawing updates from the designers.

Finally, a survey was conducted to gauge the satisfaction levels of individuals involved in the design phase. Based on 13 questions, it provided valuable insights into the overall design process. In conclusion, a summary of the main findings about the improvements in the drawing delivery and stakeholders' satisfaction with the VDC implementation was presented, in addition to further research recommendations and limitations.

CASE STUDY

This study is based on two projects located in the district of Surco in Lima, Perú. Both buildings are residential projects from a property company that uses traditional methods, including 2D models for designing and coordinating their residential buildings and non-integrated working methods in their processes.

The projects are:

- A new project started in 2023 and finished in 2024. It has 7 stories, 2 units per story, and a land area of 1700 m2.
- A former project (benchmark project) started in 2021 and finished in 2022. It has 5 stories with 2 units per story, having a land area of 1900 m^2.

Both projects were carried out by "Venti Grupo Inmobiliario" (the Company).

RESULTS

The POP Matrix and the VDC framework were developed with the client and project objectives as its focal point and the production metrics table that guided the methodology implementation during the design phase. Subsequently, the obtained results for each component during the implementation were presented. Finally, a comparison was drawn between the results of the design phase implementing the VDC methodology in the new project and those obtained in the former project of the Company.

CLIENT AND PROJECT OBJECTIVES

As a result of the interview with the project manager, it was identified that the Company aimed to initiate the presale of the new project units to obtain bank financing for starting construction in August 2023. With this in mind, the project objective was identified as reducing the time of the design stage to achieve the final architectural design by June 2023.

POP MATRIX

The company's information was graphed and integrated into the POP Matrix, as shown in Table 1, to facilitate the client's objective of understanding its operation.

Table 1: POP Matrix for the new project.

	Function	Form	Behavior
Product	Final project design deadline delivery date: June 2023	Optimizing the effectiveness of project coordination by replacing the use of CAD drawings with a BIM model.	Successfully implement BIM to replace the traditional interference detection procedure (CAD).
Organisation	Start pre-sale campaign date: June 2023	Having increased effectiveness and reduced the time for plan updates.	Having resolved issues presented within an established time frame.
Process	Improve productivity in the design stage and reduce time spent	Having established a continuous flow of drawing production to meet the established schedule.	Meeting the deadlines for deliverables for the designers.

VDC FRAMEWORK

The information obtained and graphed in the POP Matrix supported the development of the VDC framework of component objectives. Figure 2 identifies the client and project objectives based on their needs, and the proposed uses of ICE, PPM, and BIM tools aim to integrate operations among stakeholders to accomplish these objectives.

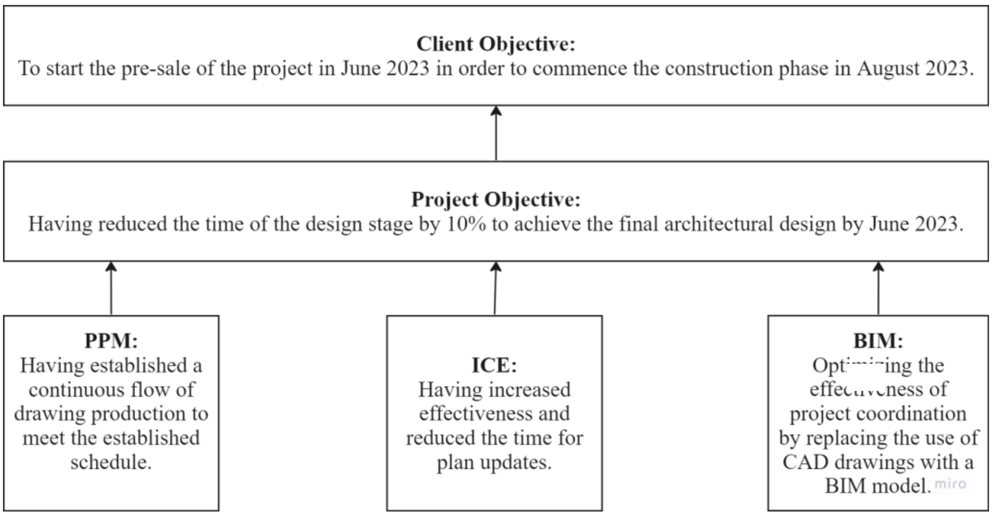

Figure 2: VDC Framework for the new project.

Next, Tables 2, 3, and 4 present the production objectives (PO) and controllable factors (CF) for PPM, ICE and BIM, respectively, along with their respective goals and sources of information.

Project Production Management (PPM)

Existing Process

The workflow was graphed based on the information the project manager gave in his interview (Figure 3). The timeline of the workflow is divided into three stages:

1. Planification: This stage's initial architectural design is carried out. This phase defines the provisional architectural design that serves as the basis for commencing the design of other specialties.
2. Stage 1: The process phase is where the specialty drawings are initially designed according to the architectural plan. Subsequently, the compatibility process begins. This process is repeated until the majority of incompatibilities and interferences are resolved.
3. Stage 2: This stage occurs after the technical file is delivered to the Municipality Office (responsible for the licenses to build) and continues until the start of construction. It may include drawing updates if required by the Municipality Office.

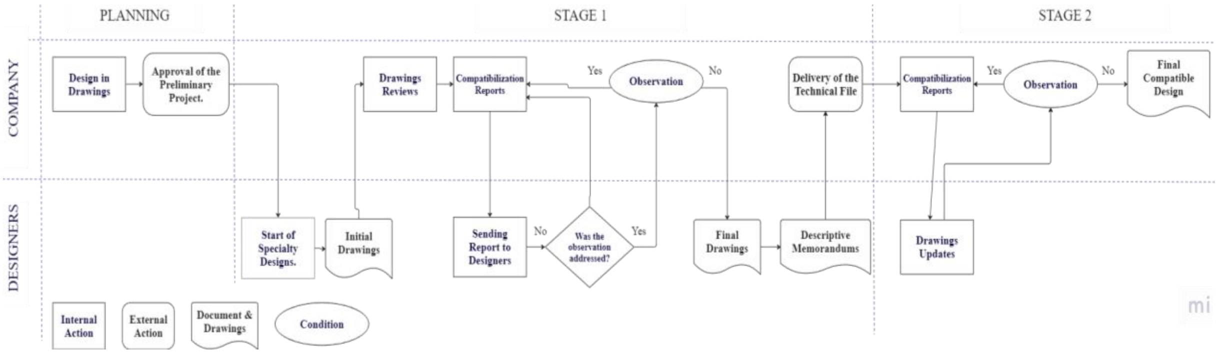

Figure 3: Traditional design workflow.

To initiate pre-sales ahead of schedule, it was necessary to reduce the time related to the design development. In the pre-sale context, obtaining architectural distribution drawings at the earliest opportunity became essential.

Proposed Process

Implementing VDC improved the design workflow using tools to enhance productivity at different process stages, as shown in Figure 4.

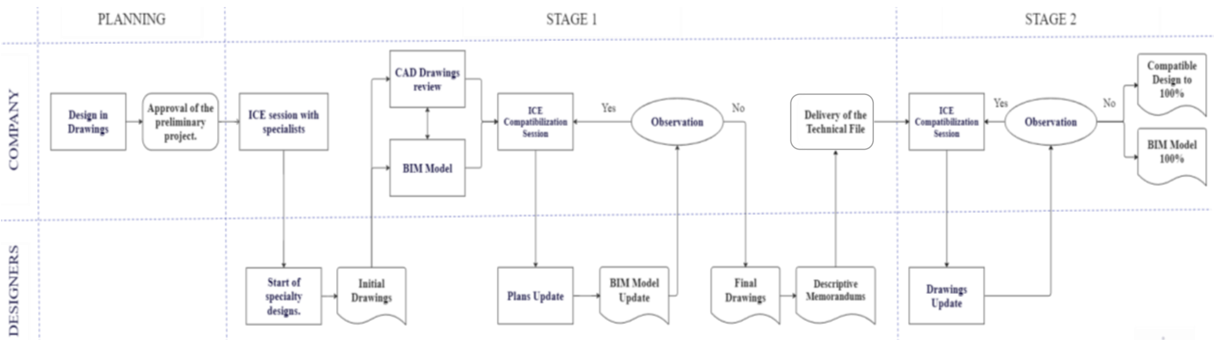

Figure 4: Improved design workflow with VDC.

The integration of the VDC methodology improved the design workflow. The proposal was presented to the Company and explained how it would improve the project's design stage. Then, the stakeholders were surveyed to validate the proposal, resulting in a 96% approval.

Utilizing a BIM model throughout the workflow allows for clarity in information among project members, enhancing coordination and information exchange in the process.

Additionally, using ICE sessions instead of email requests fosters an environment of integrated decision-making.

On the other hand, the PPM helped to complete the scheduled milestones. To achieve this, the production control was carried out using Lookahead and Takt-Time Planning tools (see Figure 5) to monitor activities performed by each designer. These activities were scheduled and worked in each ICE session. Tasks included updating drawings, preparing the descriptive memorandum, and addressing observations from non-executable tasks. The ICE sessions helped to coordinate the due tasks for the upcoming weeks and the delivery date deadlines for the design deliveries.

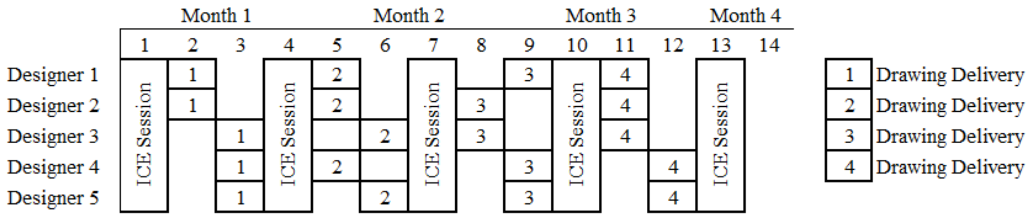

Figure 5: Takt Time Planning for task deliveries.

In the sequence, Table 2 presents the metrics table developed for the PPM component and Figure 6 shows the results obtained. The PPM production metric was tracked based on classifying the activities before the ICE sessions, which helped identify activities that could be addressed during the sessions.

Table 2: Summary of metrics for production objectives and controllable factors of PPM.

		Description	Metric	Target Value	Source of information
PPM	PO	Meeting the deadlines for deliverables from the designers.	Number of working days for the delivery of updated plans.	≥6 working days	Schedule
	CF	Classifying Lookahead activities into constrained and unconstrained activities.	Percentage of classified activities.	100% ± 10%	Lookahead

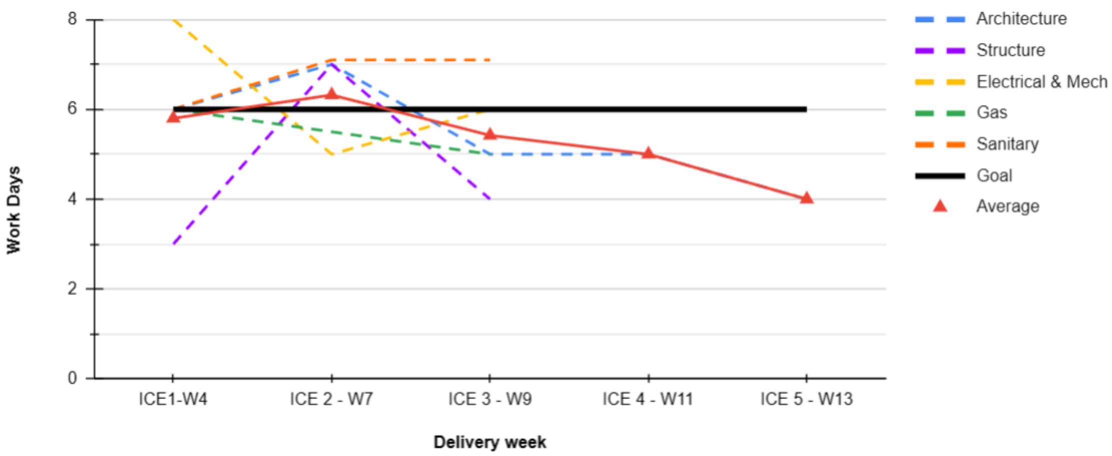

Figure 6: PPM Production Objectives: Drawings updated.

INTEGRATED CONCURRENT ENGINEERING (ICE)

Implementing ICE sessions helped to reduce issue-solve time latency by replacing email communication with sessions for real-time query resolution. These sessions were coordinated within the project management team and scheduled with relevant designers to address the decisions, such as interferences in the design.

The required information to carry out the session was provided to the designers at least three working days before the sessions, ensuring they could prepare potential solutions for discussed interferences and maximize session efficiency. Table 3 outlines ICE production metrics. To register the metrics, a control record document was employed to register all discussed issues and attendance.

ICE sessions were conducted in the project, including an initial ICE 0 session to introduce the project objective and schedule potential dates. The sessions lasted between 1 and 2 hours, during which observations were addressed, current progress was analyzed, and plans with the raised observations were scheduled.

Table 3: Summary of metrics for production objectives and controllable factors of ICE.

		Description	Metric	Target Value	Source of information
ICE	PO	Having resolved the scheduled issues during ICE sessions.	1. Percentage of issues resolved per session.	100% ± 10%	Interference Log
			2. Percentage of guest attendance.	100% ± 10%	Sessions Documentation
	CF	Working days in advance for the delivery of necessary information for the ICE session	Number of working days in advance for the delivery of information.	3±1	Emails with information submissions

BUILDING INFORMATION MODELING (BIM)

BIM helped to maximize project coordination efficiency through powerful visualization and understanding of the project within the VDC framework. This was achieved using BIM to involve the comprehensive detection and solution of interferences in the design.

BIM implementation in the project focused on the Company's transition from CAD to BIM. To assess this shift, usage incidence was compared between the two during various ICE sessions throughout the design stage. Table 4 presents the production metrics for the BIM component. The number of 2D sheets modeled measured the progress of the modeled information, and the interference log kept track of the method for detecting the incompatibility.

Table 4: Summary of metrics for production objectives and controllable factors of BIM.

		Description	Metric	Target Value	Source of information
BIM	PO	Replace the traditional interference detection procedure with the VDC proposal.	Percentage of incompatibilities detected with the BIM model.	≥75% ± 10%	Interference Log
	CF	Generate a 3D LOD 300 model to detect interferences.	Percentage of modeled information.	100% ± 10%	Revit Model

Figure 7 shows the number and percentage of interferences identified by BIM and CAD tools. Since the second session, most interferences have shifted to be identified with BIM.

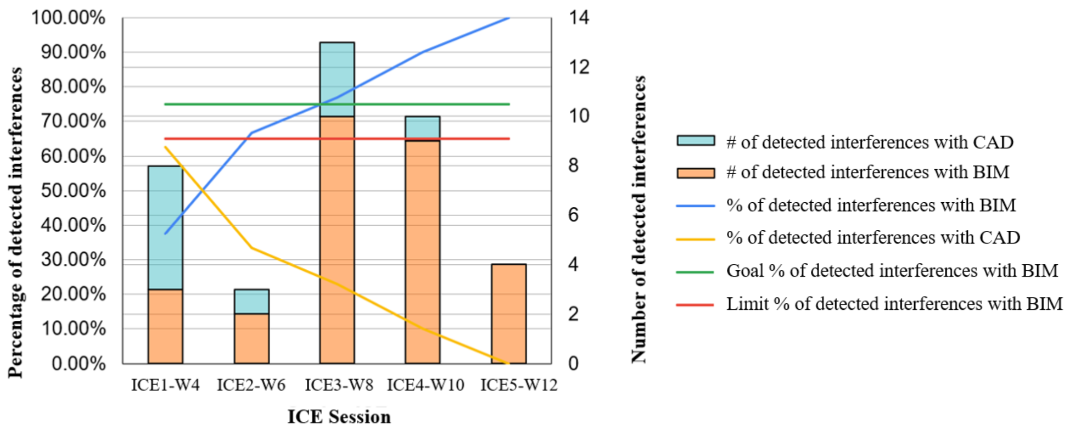

Figure 7: BIM Production Objective: incompatibilities detected.

SATISFACTION WITH THE VDC APPLICATION

Key project stakeholders were surveyed using 13 questions to evaluate the VDC application. As depicted in Figure 8, the findings show that the stakeholders expressed high satisfaction levels for nearly all questions - 12 out of 13 received the top satisfaction rank of 5 out of 5.

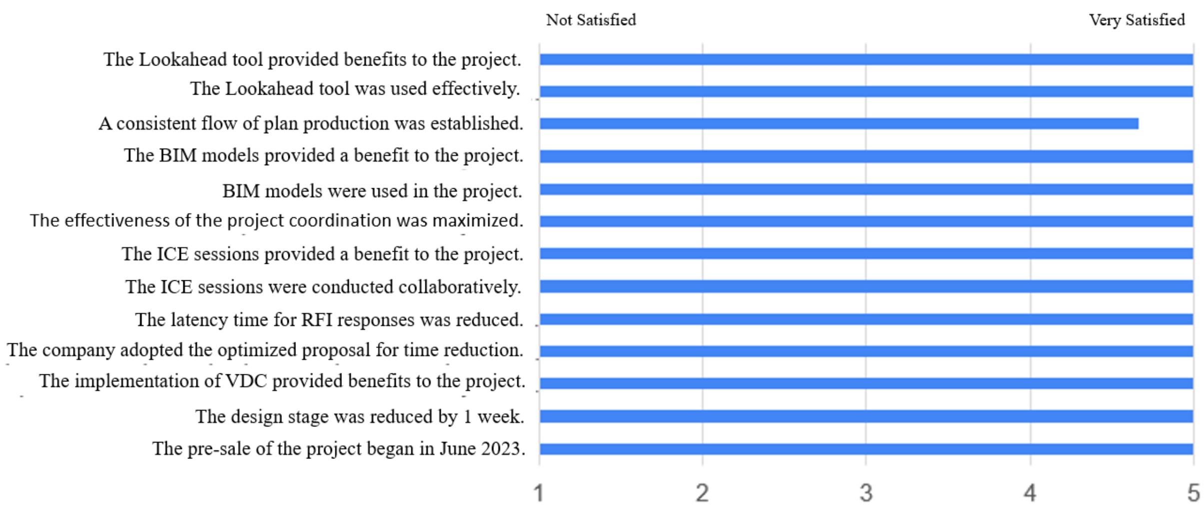

Figure 8: Stakeholder survey on the VDC application.

COMPARISON OF RESULTS

Figure 9 presents the average time required to update the drawings to assess the effectiveness of the optimized workflow for the new project using VDC compared to the traditional approach used in the former project.

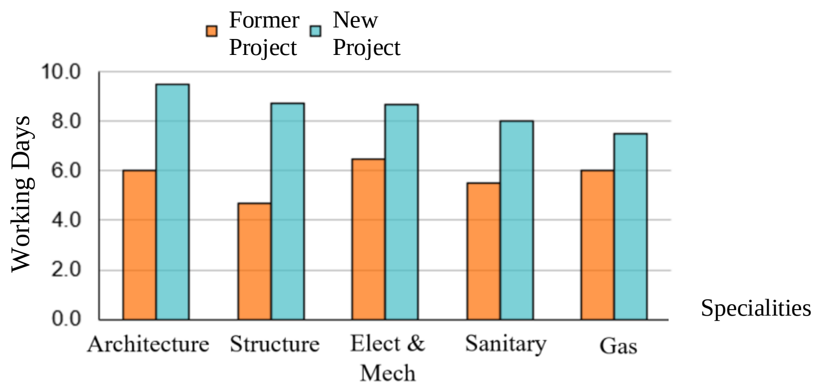

Figure 9: Average time comparisons to update drawings between the new and former projects.

DISCUSSION

The analysis of the Company's design process for the former project revealed the opportunities for improvement in several areas, including:

- Enhancing efficiency by minimizing downtime between email responses to expedite decision-making tasks.
- Streamlining the identification and solution of interferences to eliminate bottlenecks and facilitate a smoother project design process.
- Improving communication to reduce the need for constant redesigns of architecture and other specialties.
- Establishing clear information channels among participants to enhance overall clarity.
- Ensuring timely delivery of the technical files by addressing and mitigating delays in the planned schedule.

As for the results obtained, the production objectives were monitored throughout the design phase, looking to meet the objective and striving for continuous improvement. During the ICE sessions, issues were resolved using CAD or BIM. PPM production metric was tracked based on classifying the activities before the ICE sessions, facilitating identifying activities that could be addressed during the session.

The lookahead application was successful, achieving the 100% target for the controllable factor of classified tasks. This allowed identifying non-executable tasks and the respective coordination to ensure interferences could be resolved in the ICE session. In addition, a consistent production flow was maintained. Thus, achieving the goal of on-time deliveries on most agreed-upon dates resulted in a total compliance rate of 84%, above the minimum limit of 75% (see Figure 7).

The surge in BIM utilization exhibited a direct correlation with the percentage of project information that was modeled. The targeted percentage was achieved during ICE session 3 (week 8, ICE3-W8), as depicted in Figure 7, with the complete design being modeled. This contrasts ICE session 2 (week 6, ICE2-W6), where only 72% of the required information had been modeled by that point.

CONCLUSIONS

Implementing the VDC methodology has proven to be instrumental in enhancing the efficiency of the project's design stage, resulting in a remarkable 25% improvement in the time taken to deliver technical files. This notable achievement can be attributed to the systematic reduction of variability in the drawings update process, the effective identification and resolution of interferences through BIM, collaborative problem-solving in ICE sessions, and the establishment of standardized production timelines for updated drawings using PPM.

The proposed optimized process, designed for ease of use as a collaborative management tool, holds significant potential for property companies during the design stage. This is corroborated by the high satisfaction levels and adaptability expressed by the project stakeholders in surveys conducted on VDC implementation.

Furthermore, the pivotal role of BIM in detecting project interferences is underscored, with the degree of success directly proportional to the availability and modeling of project information. This proactive approach allows for the improved detection of most interferences in the project's early stages.

Emphasizing the critical nature of active stakeholder participation in ICE sessions, the research highlights the necessity of collaborative decision-making to resolve interferences promptly. The ICE sessions facilitate real-time problem-solving and ensure the timely updating of drawings, contributing to the project's overall success.

This research's main contribution is an optimized design process with VDC that can be applied in similar construction projects. It addresses construction industry challenges with the application of VDC and demonstrates its effectiveness in reducing design delivery time, resolving interferences and improving stakeholders' satisfaction.

This investigation is limited to projects and companies sharing similar characteristics. It is important to note that more complex and bigger projects can face different problems, and their application process could differ. The project's design phase schedule limited the resources and times for the proposal and the VDC framework application. Additional resources and time can enable the development of procedures and manuals for the current application.

For future investigations, it is recommended that an economic evaluation of the proposed implementation be conducted, which should include the additional costs and savings generated by the optimized process.

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