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Development and Analysis of Five-Dimensional BIM in Construction Management, Case Study – Multifamily Housing

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Abstract **-** The construction of multifamily housing in Metropolitan Lima faces challenges in efficiency, cost control, and sustainability. This article analyzes the implementation of five dimensions of Building Information Modeling (BIM) in a multifamily housing project, evaluating how this methodology optimizes planning, design, costs, and construction timelines. Through a case study and a survey of local professionals, the benefits of BIM in project management and the barriers to its adoption in Peru, such as the lack of training and initial costs, are explored. The results indicate that BIM improves coordination, reduces errors, and optimizes resources, offering a promising approach for sustainable construction in emerging markets.

Keywords**:** Housing construction, BIM, project management, five dimensions, sustainability, Metropolitan Lima.

1. Introduction

The construction industry in Metropolitan Lima is currently experiencing a significant increase in the demand for multifamily housing, driven by population growth and urbanization in the region. This scenario presents major challenges for the sector in terms of efficiency, cost control, and sustainability in construction processes, aspects that directly impact the economic and environmental viability of projects. The pressure to meet this demand while maintaining quality standards and adhering to set timelines forces companies to seek alternatives that allow for better resource management and improved on-site coordination—areas where traditional planning and control methods have proven limited in their effectiveness.

Despite the multiple advantages it offers, the adoption of BIM (Building Information Modeling) technology in Peru is still in its early stages. BIM has emerged as a tool with great potential to transform the construction industry globally, and its application in five dimensions—which includes everything from 3D modeling to 4D scheduling and 5D cost integration—significantly enhances precision and efficiency in project execution. However, the adoption of BIM in multifamily housing projects in Lima faces considerable challenges, such as a lack of adequate training for professionals, a lack of standardization in processes, and a minimal organizational culture oriented towards innovation. These factors not only hinder the effective implementation of BIM but also highlight the need for policies and government support to promote its use, as well as a business infrastructure ready to adapt to new technologies.

The global implementation of BIM has been studied in various contexts, demonstrating both its benefits and the challenges of adoption across different industries and regions. In Brazil, Arrotéia [1] identified that the lack of standards and government policies, along with a lack of awareness among professionals, limits BIM adoption, recommending greater collaboration and training in this technology. In Colombia, Osorio-Gómez [2] developed a model for digital transformation in construction, emphasizing the role of BIM in enhancing productivity and efficiency in the sector. In Peru, Pacheco [3] assessed the feasibility of BIM in local projects, indicating that proper integration of 3D, 4D, and 5D dimensions could contribute to greater accuracy in design and planning. In Malaysia, Waqar [4] and Rahim [5] analyzed the positive impacts of BIM on collaboration and standardization in the sector, emphasizing that training and government support are crucial for effective adoption in residential construction projects. These studies highlight that BIM implementation faces cultural, technical, and economic barriers, especially in developing countries, and suggest strategies such as continuous training and integration of interdisciplinary teams to overcome these challenges. Additionally, recent studies underscore the importance of data interoperability in BIM. Biljecki [6] addresses data loss during format conversions, proposing improvements to ensure efficient data transfer. Khalili [7] explores the use of geo-

semantic data in virtual reality, while Xu [8] investigates the integration of BIM with life cycle assessments (LCA), which allows for evaluating environmental impacts through better material and resource management.

This article aims to analyze how the implementation of BIM in five dimensions can optimize the management of multifamily construction projects in Metropolitan Lima, referencing a local case study. It also addresses the main challenges faced by the adoption of this technology in the Peruvian context, exploring how these obstacles could be overcome through strategies such as continuous training, strengthening interdisciplinary collaboration, and standardizing procedures.

2. TOOLS, MATERIALS, METHOD AND METHODOLOGY

This study implemented a methodology based on the five dimensions of BIM in a multifamily housing construction project in Metropolitan Lima, specifically in the Alberto Alexander project. The research was conducted in three main stages: 3D modeling in Revit, integration of costs and scheduling in Navisworks, and data collection through a survey directed at sector professionals to assess both the applied methodology and the perception and context of BIM adoption in multifamily housing projects in the region.

In the first stage, Revit software was used for 3D modeling of the architecture and structure of the project (Figure 1 and Figure 2). The goal was to create an accurate and detailed representation of the building, serving as a solid foundation for planning and coordination of each construction component. Revit provided a collaborative environment where all building elements, such as walls, beams, and columns, were modeled in detail, facilitating precision and consistency in the later stages of time and cost management.

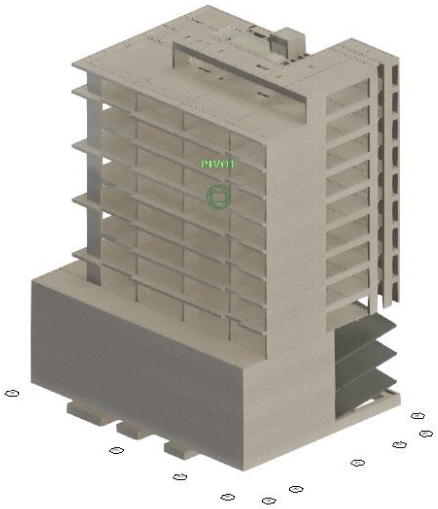


Figure 1. Structural modeling in Revit

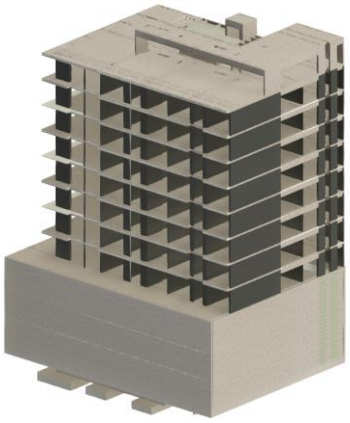
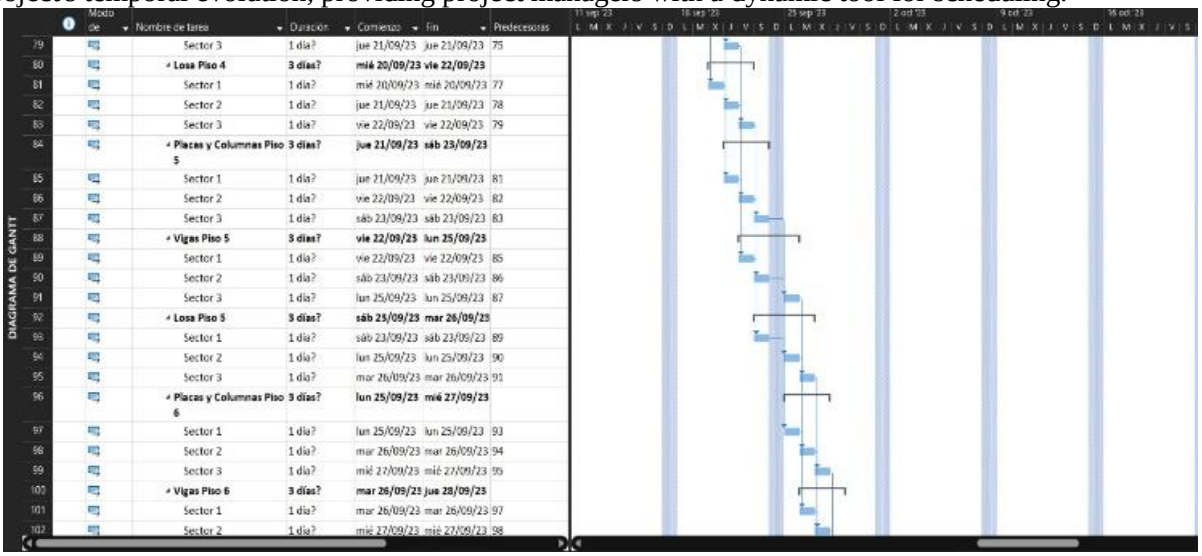


Figure 2. Architectural modeling in Revit

The second stage focused on the integration of the 4D and 5D BIM dimensions using Navisworks. Here, a construction schedule developed in MS Project was imported, allowing synchronization of project activities with the 3D model in Navisworks (Figure 3). This integration enabled the simulation of construction sequences and visualization of the project's temporal evolution, providing project managers with a dynamic tool for scheduling.



	Modo de	Nombre de tarea	Duración	Comienzo	Fin	Predecesoras
79		Sector 3	1 día?	jue 21/09/23	jue 21/09/23	75
80		**Losa Piso 4**	**3 días?**	**mié 20/09/23**	**vie 22/09/23**	
81		Sector 1	1 día?	mié 20/09/23	mié 20/09/23	77
82		Sector 2	1 día?	jue 21/09/23	jue 21/09/23	78
83		Sector 3	1 día?	vie 22/09/23	vie 22/09/23	79
84		**Placas y Columnas Piso 5**	**3 días?**	**jue 21/09/23**	**sáb 23/09/23**	
85		Sector 1	1 día?	jue 21/09/23	jue 21/09/23	81
86		Sector 2	1 día?	vie 22/09/23	vie 22/09/23	82
87		Sector 3	1 día?	sáb 23/09/23	sáb 23/09/23	83
88		**Vigas Piso 5**	**3 días?**	**vie 22/09/23**	**lun 25/09/23**	
89		Sector 1	1 día?	vie 22/09/23	vie 22/09/23	85
90		Sector 2	1 día?	sáb 23/09/23	sáb 23/09/23	86
91		Sector 3	1 día?	lun 25/09/23	lun 25/09/23	87
92		**Losa Piso 5**	**3 días?**	**sáb 23/09/23**	**mar 26/09/23**	
93		Sector 1	1 día?	sáb 23/09/23	sáb 23/09/23	89
94		Sector 2	1 día?	lun 25/09/23	lun 25/09/23	90
95		Sector 3	1 día?	mar 26/09/23	mar 26/09/23	91
96		**Placas y Columnas Piso 6**	**3 días?**	**lun 25/09/23**	**mié 27/09/23**	
97		Sector 1	1 día?	lun 25/09/23	lun 25/09/23	93
98		Sector 2	1 día?	mar 26/09/23	mar 26/09/23	94
99		Sector 3	1 día?	mié 27/09/23	mié 27/09/23	95
100		**Vigas Piso 6**	**3 días?**	**mar 26/09/23**	**jue 28/09/23**	
101		Sector 1	1 día?	mar 26/09/23	mar 26/09/23	97
102		Sector 2	1 día?	mié 27/09/23	mié 27/09/23	98

Figure 3. Importing the MS Project schedule into Navisworks

Additionally, estimated costs for each family of structural elements were manually entered, maintaining the confidentiality of specific project data. This process allowed for detailed financial control, aiding in the projection of the overall budget and comparing planned progress with actual construction progress, thereby facilitating efficient resource management (Figure 4).

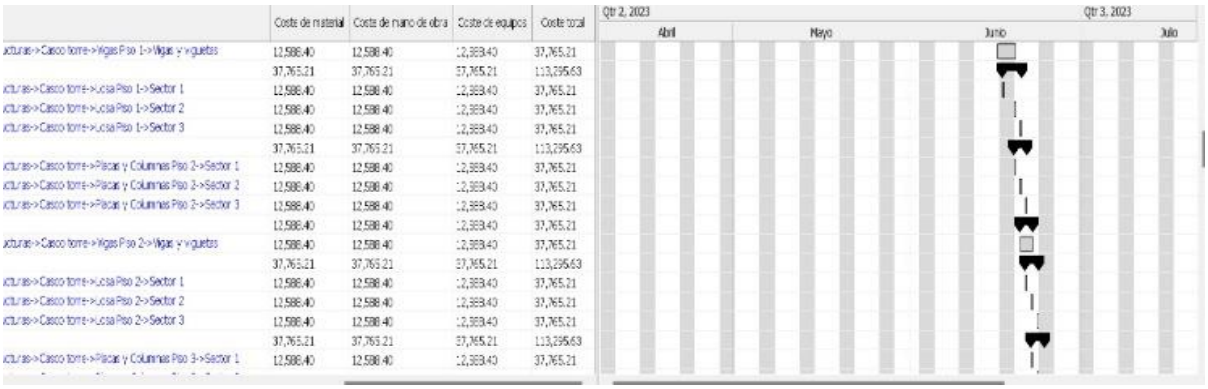


Figure 4. Cost integration in Navisworks

Finally, a simulation was generated showing project progress with the accumulated cost displayed in the upper left corner of the screen, enabling real-time observation of expenses according to the progress of each construction phase (Figure 5 and Figure 6). This simulation provides a comprehensive view of time and cost control for the project.

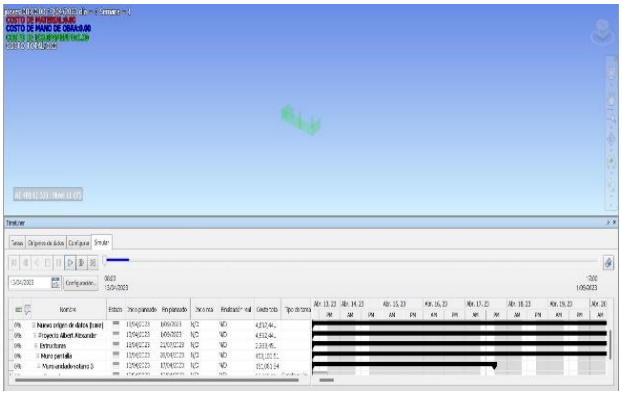


Figure 5. Start of project progress simulation with cost control in Navisworks

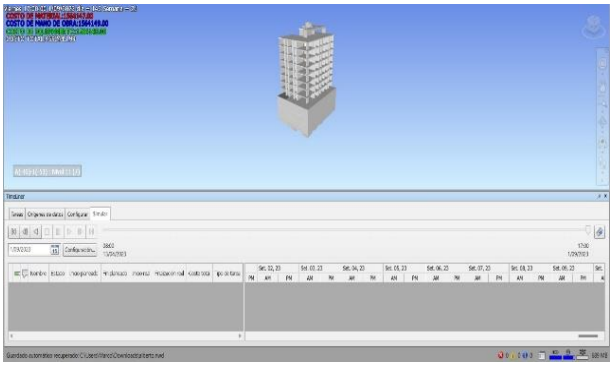


Figure 6. End of project progress simulation with cost control in Navisworks

In the third and final stage, a survey was conducted targeting professionals in the sector, including construction site residents, production engineers, technical office staff, and other specialists experienced in BIM implementation. The survey contained 16 multiple-choice questions designed to capture perceptions of the benefits, challenges, and opportunities of BIM adoption in Metropolitan Lima. To ensure the representativeness of the results, a sample size

was calculated considering an estimated population of 2,100 professionals, based on the 700 active projects in the city and an average of three civil engineers per project. With a confidence level of 85% and a margin of error of ±17.5%, a sample of 14 participants was deemed adequate for the purposes of this study. As can be appreciated in Equation 1, the sample size calculation takes into account these parameters to provide an accurate representation.

$$n = \frac{2100 \cdot 1.44^2 \cdot 0.3 \cdot (1-0.3)}{0.175^2 \cdot (2100-1) + 1.44^2 \cdot 0.3 \cdot (1-0.3)} \cong 14 \quad (1)$$

The survey results were analyzed using bar charts and pie charts that helped visualize trends and facilitated data interpretation, providing an additional perspective on the current state and expectations regarding BIM in multifamily housing construction in Lima. This analysis complemented the findings of the earlier stages, confirming the usefulness of BIM in optimizing construction processes and highlighting challenges related to training and standardization in the local context.

Furthermore, the study emphasizes the importance of conducting a return on investment (ROI) analysis for BIM adoption in Peru, considering that doubts still persist in the sector regarding its long-term profitability. The economic benefits assessment from specific case studies could demonstrate BIM's positive impact, thereby encouraging its use in the industry.

3. RESULTS

With the aim of validating the content developed in this research on the application of the five BIM dimensions in the management of multifamily housing construction projects, a survey was conducted targeting a diverse group of professionals and workers involved in the construction sector. The purpose of this survey was to collect data that would allow for the evaluation of both theoretical knowledge and practical experience related to the use of BIM, specifically in the context of multifamily housing projects in Metropolitan Lima.

The target audience for the survey included a variety of professional profiles playing key roles in construction project management. Participants included construction site residents, those directly overseeing field activities, technical office staff responsible for design, planning, and project supervision, and production engineers focused on execution and resource optimization during construction. This diversity of participants enabled the collection of a range of opinions and experiences, contributing to a more comprehensive analysis of the use and perception of BIM in the field of multifamily housing construction.

The survey consisted of 16 questions, 14 of which were multiple-choice with five response options: Very High, High, Moderate, Low, and Very Low. These questions were designed to assess the level of knowledge, acceptance, and application of the various BIM dimensions (3D, 4D, 5D) in construction project management. The responses were grouped according to the categories mentioned to facilitate analysis and visualization in bar charts.

The other 2 questions allowed for selecting multiple options and, therefore, could not be analyzed using the "Very High," "High," "Moderate," "Low," and "Very Low" categories. These questions were assessed using pie charts, providing a clear representation of the different responses selected by the participants.

Below are the results obtained from the survey responses, which provide an overview of the level of knowledge, acceptance, and application of BIM in multifamily housing construction projects in Metropolitan Lima. These results not only provide a solid foundation for understanding the professionals' perception of BIM adoption in the local context but also highlight key areas for improving its implementation, identifying both challenges and opportunities for optimization in the use of this technology.

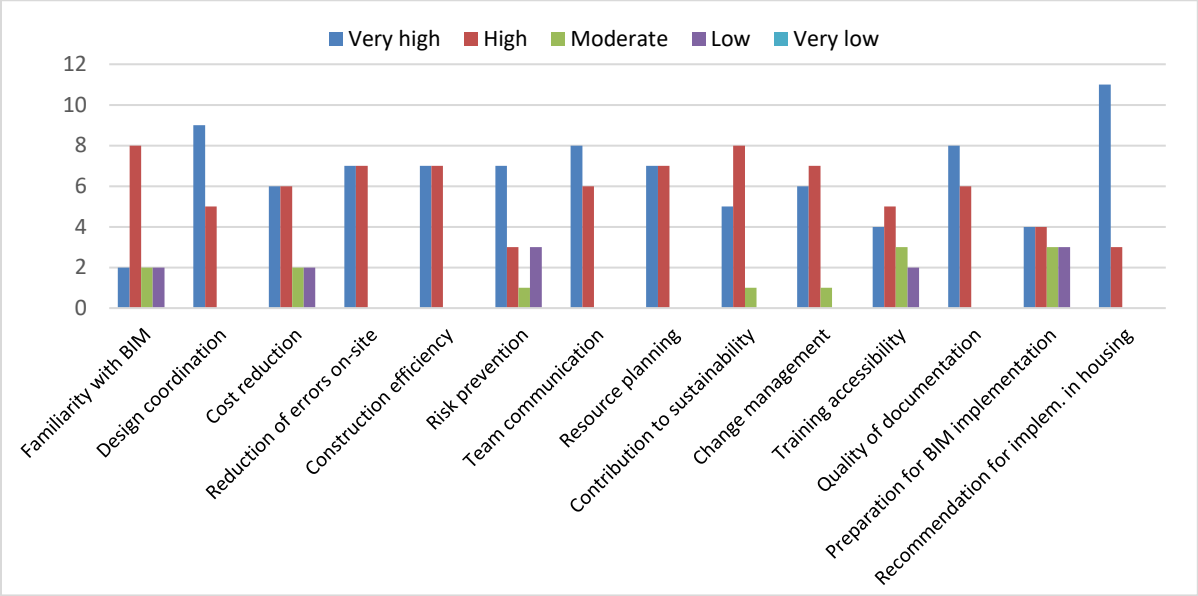


Figure 7. Evaluation of the Impact of BIM on Construction Project Management

In the 14 questions evaluated with response options "Very High," "High," "Moderate," "Low," and "Very Low" (Figure 7), the results reflect an overwhelmingly positive perception of BIM in construction projects. Overall, most responses were concentrated in the "Very High" and "High" categories, indicating a widespread recognition of the benefits of implementing BIM in various areas of project management. For example, 100% of respondents agreed that BIM has a very high or high impact on improving design coordination, highlighting its ability to integrate various disciplines and reduce conflicts among project stakeholders. Additionally, efficiency in reducing errors on-site was another fully supported aspect, showing that professionals value BIM's ability to minimize errors during execution, which helps reduce costs and improve planning.

Regarding BIM's ability to reduce costs, 86% of respondents perceived it positively (very high or high), although 14% rated its impact as moderate or low, which could be related to the initial cost of implementing BIM and the lack of visibility of its short-term benefits. Similarly, improvements in construction process efficiency were also highly valued, with 100% positive responses, reaffirming the perception of BIM as a key tool for optimizing project planning and execution.

Time control on-site was also recognized as one of BIM's main benefits, with detailed planning being highlighted as the most relevant aspect. Improving communication between teams was another key aspect, with 100% of respondents indicating that BIM facilitates the transmission of accurate and up-to-date information, improving coordination and reducing misunderstandings. Regarding risk prevention on-site, 71% considered BIM to have a high or very high impact, while 29% expressed a moderate or low perception, suggesting that BIM could be more effectively integrated with on-site safety management systems.

On the other hand, BIM's contribution to sustainability was highly rated (93% in "Very High" or "High"), highlighting its potential to optimize material usage, reduce energy consumption, and lower carbon emissions. However, a small percentage (7%) rated it as moderate, indicating that while most see value in sustainability, there are still areas for improvement. Finally, the unanimous recommendation to implement BIM in multifamily housing projects underscores the widespread importance of this technology in improving efficiency, quality, and sustainability in project management.

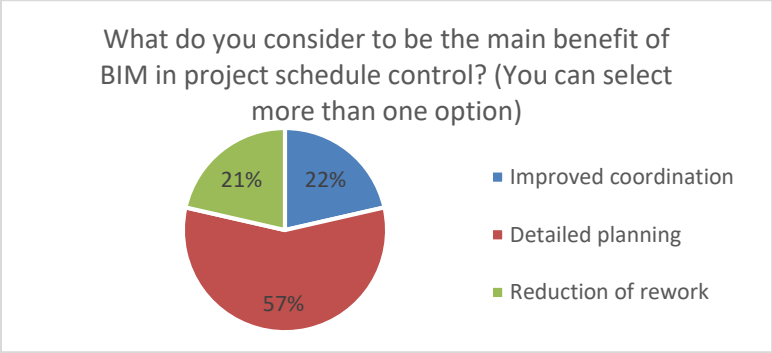


Figure 8. Distribution of responses to the question: What do you consider to be the main benefit of BIM in time control on-site? (Multiple options can be selected)

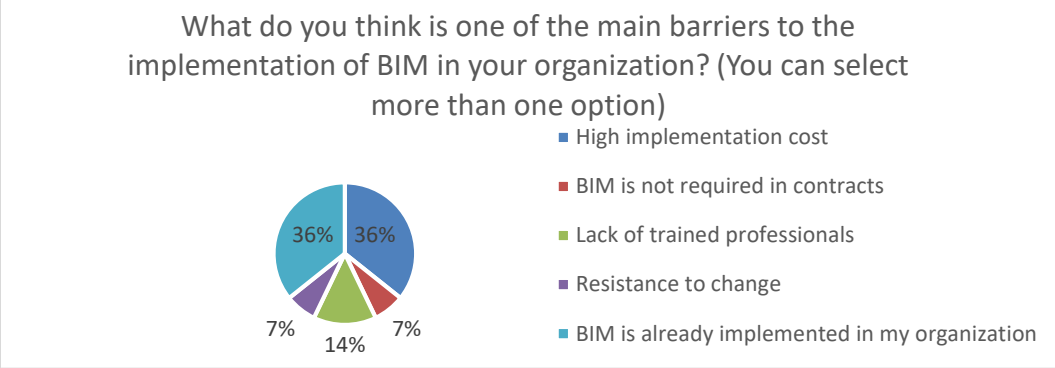


Figure 9. Distribution of responses to the question: What do you think is one of the main barriers to BIM implementation in your organization?

For these two questions that allowed multiple options to be selected and are presented in pie charts (Figure 8 and Figure 9), a more detailed and specific view was obtained regarding the benefits and barriers associated with BIM implementation in construction projects. The question on BIM benefits in time control on-site revealed that detailed planning, reduced rework, and improved coordination were considered the main advantages. This shows that respondents value how BIM contributes to optimizing project schedules, minimizing delays, and improving time management efficiency.

On the other hand, the question about the main barriers to BIM implementation showed that the most frequently mentioned challenges were the lack of skilled professionals and the high cost of implementation. These responses reflect concerns about the human and economic resources needed for effective BIM adoption. Additionally, resistance to change was noted as a minor barrier, suggesting that while some professionals may be reluctant to adopt new technologies, in general, the willingness to incorporate BIM appears to be increasing. These results highlight key areas for improvement, such as the need for more training and better justification of BIM's return on investment (ROI) to overcome economic and staffing barriers to implementation.

4. VALIDATION

To validate the findings obtained from the applied survey, expert judgment in BIM implementation in construction projects was sought. This validation process aimed to confirm that the survey results, particularly regarding improvements in coordination, cost reduction, and project management efficiency, align with current best practices and trends in the construction sector. The consulted experts confirmed that the benefits perceived in the survey, such as the

optimization of construction processes and the improvement of time and resource planning and control, reflect effective BIM adoption, which is consistent with global advancements in the use of this technology.

The experts also highlighted that reducing errors on-site is one of the main benefits of implementing BIM, as it facilitates coordination between disciplines and enhances real-time communication. This ability to prevent conflicts and ensure more precise execution is crucial for avoiding cost overruns and delays. However, they also emphasized that there are barriers that need to be overcome, such as the lack of trained professionals and high initial costs for BIM implementation. Nevertheless, it was agreed that the successful adoption of BIM in multifamily housing projects in Metropolitan Lima is feasible if adequate strategies are in place, such as specialized BIM training and strong organizational commitment to its implementation.

Expert judgment complements and validates the survey results, strengthening this study's proposal regarding the feasibility and benefits of adopting BIM in construction project management in Metropolitan Lima. Experts stressed that, in addition to ongoing training, an organizational strategy that supports innovation and fosters the integration of new technologies into company culture is essential. BIM implementation should be a gradual process involving all project stakeholders, from designers to contractors, including field engineers.

Furthermore, the experts indicated that BIM adoption can be accelerated through continuous training programs within companies and the incorporation of government policies that provide incentives, such as tax benefits and grants, to firms that implement this technology. These incentives would not only reduce the financial burden of initial adoption but also encourage more companies, especially medium and small-sized enterprises, to consider BIM as a viable option.

The standardization of processes and improved communication among stakeholders at each project stage were identified as crucial measures for BIM implementation success. Likewise, the importance of strengthening an organizational culture that promotes innovation and continuous learning was emphasized, valuing the adoption of new technological tools and encouraging collaboration among all involved in the projects.

This validation process of the findings through expert judgment has not only reinforced the idea that BIM is a valuable tool for construction project management but has also provided a stronger framework for its successful implementation. By incorporating both the survey results and expert recommendations, this study reinforces the need to strategically adopt BIM with a comprehensive approach that considers both the benefits and barriers associated with its implementation.

5. CONCLUSIONS

The study on the implementation of the five dimensions of BIM in the management of multifamily housing construction projects has provided valuable evidence of the positive impacts of this technology in the construction industry. The results obtained from the survey demonstrate that BIM adoption has a significant impact on improving coordination among work teams, reducing costs, enhancing process efficiency, and controlling project timelines. Most respondents recognized that BIM notably contributes to the optimization of construction processes, particularly in reducing on-site errors, improving resource planning accuracy, and simplifying project documentation and reporting.

Specifically, the survey revealed that a high percentage of participants believe that BIM implementation facilitates communication and collaboration among the different teams involved in the project. This aspect is crucial, as the ability to share information in real-time and in a centralized manner improves decision-making and allows stakeholders to access updated data, significantly reducing errors and coordination issues common in traditional construction projects. However, key challenges limiting its widespread adoption were also identified, such as the lack of specialized BIM training and high initial implementation costs. These obstacles are particularly relevant in the context of Metropolitan Lima, where many construction sector companies face economic constraints and limited human resources trained in this technology.

Despite these challenges, most respondents agreed that, to maximize BIM's potential in the multifamily housing construction sector, continuous and specialized training programs are essential. This training should be designed to

prepare industry professionals in the proper use of BIM tools and processes, enabling them to take full advantage of this technology's benefits. Additionally, the study highlights the importance of adopting institutional and governmental policies that promote BIM implementation, such as creating incentives and tax subsidies, which can alleviate the initial costs associated with BIM adoption and facilitate its uptake by companies of various sizes.

At the organizational level, the study concludes that companies in the sector should adopt a culture of innovation and continuous improvement, recognizing the transformative potential of tools like BIM to enhance project planning and execution processes. It is essential for companies to understand that investing in BIM not only improves efficiency and reduces costs but also has a long-term positive impact on the quality and sustainability of projects. Therefore, it is recommended that companies explore alternatives, such as monthly memberships or shared licenses, to reduce initial adoption costs and make BIM use more accessible. Additionally, a detailed return on investment (ROI) analysis should be conducted to demonstrate the economic benefits BIM can generate over the long term.

The improvement in communication and collaboration among work teams, facilitated by BIM's capability to share real-time information, further reinforces the value of this tool in the construction context. BIM not only optimizes technical processes but also fosters a more collaborative and efficient work environment, which is crucial for the successful management of large-scale projects, such as multifamily housing.

Finally, this study provides valuable evidence of the advantages and challenges associated with BIM implementation in the construction sector in Metropolitan Lima. While there are barriers to adoption, the long-term benefits are undeniable. With appropriate support from both the public and private sectors, BIM has the potential to significantly transform project management in construction, enhancing the quality, efficiency, sustainability, and competitiveness of the construction sector in Metropolitan Lima. This study suggests that BIM adoption is a promising path for modernizing the construction industry, especially in a context where technological innovation is becoming a key factor for sector development.

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