ISBN: 978-628-96613-3-0. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2026.1.1.307

Preliminary assessment of the impact of BIM use during the construction of road projects in Arequipa, Peru

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Abstract– *This study evaluates the impact of Building Information Modeling (BIM) applications on road construction projects in Arequipa, Peru. Using a mixed-methods design, data were collected through structured surveys of 68 professionals and analyzed with the Relative Importance Index (RII), Kruskal–Wallis tests, and Multiple Correspondence Analysis (MCA). Three BIM applications were assessed: 3D modeling, interference analysis, and 4D planning. Results show that 3D modeling had the greatest positive impact (average score of 4.02), particularly in mitigating delays related to planning and monitoring. Interference analysis was highly valued for reducing design changes, while 4D planning contributed to improved scheduling accuracy. MCA revealed strong associations between professional roles, experience levels, and perceived BIM impact, underscoring the contextual factors that shape BIM adoption in emerging regions. This study provides the first empirical evidence of BIM's utility in the road sector of Arequipa and highlights its potential to address chronic delays and inefficiencies in Peru's road infrastructure. The findings contribute to broader discussions on technology adoption in developing contexts and offer guidance for practitioners and policymakers seeking to improve project performance.*

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Keywords: BIM, 3D modeling, 4D planning, road restructuring, productivity.

I. INTRODUCTION

Road infrastructure is a strategic component of economic and social development, linking productive sectors and enabling the efficient mobility of goods and people [1]. The design, planning, and execution of road projects must therefore align with contemporary requirements for efficiency, sustainability, and quality [2]. Yet in recent years, the sector has faced persistent constraints, including resource scarcity and pressure to meet tight deadlines [3]. These challenges have negatively affected project performance, as reflected in the 2023 Public Investment Management Index (IGEIP), which reported a score of 0.363 for Peru's transport and communications sector—evidence of poor time management and execution [4]. Inadequate planning during the construction phase thus emerges as a critical obstacle, underscoring the need for technological tools such as Building Information Modeling (BIM) to improve planning, optimize processes, and ensure timely delivery of quality projects [3], [5], [6].

BIM is a collaborative methodology for creating and managing construction project information through three-dimensional digital models that integrate properties, volumes, materials, and specifications across the infrastructure life cycle. Core applications include 3D modeling, which represents spatial conditions with varying levels of detail (LOD) [7][8]; interference analysis, which detects conflicts between design elements; and 4D planning, which incorporates the temporal dimension into models to enhance scheduling accuracy [9]. Road infrastructure, encompassing arterial roads, streets, and complementary works in both urban and rural contexts [10], presents unique challenges that make BIM particularly relevant. As Fadeyi [11] emphasized, BIM functions as a systematic repository of knowledge, facilitating information exchange and decision-making. Shen [12] further argued that BIM improves risk identification and project management, while Han [13] demonstrated measurable gains in safety and cost efficiency through dynamic simulations. Miao [14] highlighted the value of visualization tools for knowledge management and coordination, whereas Zhang [15] noted unresolved difficulties due to the absence of standardized BIM data structures in the road sector. Different studies have shown that evaluating the perceived impact of BIM is not only appropriate but necessary in the early stages of adoption. Indicating that perception acts as a reliable indicator of how organizations internalize new processes and technologies. Gledson and Greenwood [16] highlight that professional perception captures how practitioners interpret BIM's influence on planning quality and coordination. Likewise, Khosrowshahi and Arayici [17] identify perception as a key driver in shaping BIM maturity trajectories within organizations. These two works provide evidence that supports that assessing perceived impact offers meaningful insight into how BIM is understood as a tool for improving planning effectiveness and reducing delays in real project environments.

Other studies reinforce BIM's potential but also reveal limitations. Pérez [18] identified 70 delay factors in construction projects and concluded that BIM is essential for traceability, interference detection, and 4D planning. Nielsen [19] observed that BIM adoption in road infrastructure is less mature than in building projects, reflecting greater modeling complexity. Castañeda [3][20] evaluated 39 BIM uses, identifying seven strategic applications—including cost estimation, equipment planning, and 4D scheduling—while also noting persistent scheduling limitations. Complementary research has demonstrated synergies between BIM and Lean Construction, showing that 4D visualization reduces variability and shortens execution cycles [21], and that integrating BIM with communication management can increase performance by up to 13% [22]. Zavala et al. [6] further demonstrated that combining BIM with methodologies such as Virtual Design and Construction (VDC), Project Production Management (PPM), and Integrated Concurrent Engineering (ICE) achieved a 100% resolution rate for conflicts and improved scheduling accuracy.

Despite these advances, BIM adoption in Peru's road sector remains limited. Most projects continue to rely on traditional methods, resulting in design changes, inaccurate measurements, and weak monitoring. The chronic delays observed in Arequipa's road projects, reflected in the national IGEIP score, highlight the urgency of adopting more effective planning tools. Nevertheless, no systematic evaluation of BIM's impact has been conducted locally, leaving practitioners and policymakers without evidence to guide implementation. Addressing this gap requires quantifying BIM's influence on delay factors and analyzing its associations with professional roles and experience.

Recent work by Castañeda et al. (2025) provides one of the few systematic analyses focused specifically on BIM use to mitigate planning deficiencies in road scheduling [3]. Their findings highlight persistent issues related to planning accuracy, quantity estimation, and design inconsistencies in road projects. However, their study does not examine how professional roles, experience levels, or contextual conditions influence the perceived impact of BIM dimensions that remain underexplored in emerging regions. This pattern is consistent with findings from Honnappa (2022) [23], Muhammad (2019) [24], and Succar (2008) [25], who emphasize that BIM adoption dynamics depend strongly on organizational maturity and contextual readiness.

Recent reviews in developing countries show that BIM-related performance issues tend to concentrate on a small number of critical factors rather than on extensive taxonomies. A synthesis of 124 empirical studies identified only five dominant barriers despite substantial contextual diversity, indicating that a focused set of variables is sufficient to capture the main sources of performance variation. Studies that evaluate the entire construction system—encompassing buildings, industrial facilities, and infrastructure—naturally report long lists of delay factors, reflecting the sector's complexity and heterogeneity. However, when the scope is restricted to road infrastructure, previous research consistently highlights design changes, measurement inaccuracies, and deficiencies in planning and control as the most recurrent and influential causes of delay. Takyo et al work reinforces the convergence, demonstrating that, in road projects, a reduced but representative set of factors is both methodologically appropriate and aligned with the empirical patterns documented in the literature. Takyi-Annan 2023 [26].

Building on the BIM uses identified by Castañeda [3] and the delay factors highlighted by Pérez [18], this study evaluates the impact of three BIM applications—3D modeling, interference analysis, and 4D planning—on road construction projects in Arequipa, Peru. Using a cross-impact matrix, expert-validated surveys, and statistical techniques including the Relative Importance Index (RII), Kruskal–Wallis tests, and Multiple Correspondence Analysis (MCA) [27], the research provides the first empirical validation of BIM's utility in Peru's road sector. By quantifying its influence and exploring role-specific perceptions, the study offers evidence to guide practitioners and policymakers in adopting BIM to improve project performance and reduce chronic inefficiencies.

II. METHODOLOGY

This study used a mixed-methods approach with a qualitative focus, adopting a non-experimental design and collecting data through structured surveys administered to participants with experience in road construction projects. The population consisted of all those directly involved in the projects, resident engineers, production engineers, and technical office technicians from different projects. The instrument was validated by expert judgment, and a reliability test (Cronbach's alpha) was used to assess the consistency of the questionnaire.

A. Procedure

This research was divided into three stages, as detailed below:

First stage: consisted of structuring the matrix through a literature review and expert opinion. The uses with the greatest impact on projects were selected, as shown in Table 1, as well as the main factors causing delays in the construction of road projects, as indicated in Table 2 and the matrix to be evaluated in Table 3, where the Likert scale indicated in Table 4 was used, and a scale of 0-1 was added, which is in parentheses, in order to compare with other studies.

Table 1: BIM uses in road projects

Identification	BIM use
U1	3D modeling of existing and projected conditions.
U2	Interference analysis.
U3	4D analysis and planning.

Table 2: Factors causing delays in construction

Identification	Delay factors
F1	Design changes during construction
F2	Poor estimation of measurements
F3	Lack of monitoring and control of planning

Table 3: BIM Impact Assessment Matrix

Delay factors	3D modeling of existing and projected conditions	Interference analysis.	4D analysis and planning.
Design changes during construction	1-5 (0-1)	1-5 (0-1)	1-5 (0-1)
Poor measurement estimates	1-5 (0-1)	1-5 (0-1)	1-5 (0-1)
Lack of planning, monitoring, and control	1-5 (0-1)	1-5 (0-1)	1-5 (0-1)

Subsequently, the survey was designed and divided into two parts. The first part was dedicated to gathering information on four key aspects: profession, academic degree, years of experience, and main role during project participation. The second part of the survey focused on compiling the impact of BIM use on delay factors. For this purpose, a five-point Likert scale was used, where:

Table 4: Rating table for Likert scale

Value	Description
1	Very low impact
2	Low impact
3	Medium impact
4	High impact
5	Very high impact

The survey was conducted online to facilitate sharing, and it's worth noting that two experts reviewed it. To ensure the survey's reliability, we conducted the Cronbach's alpha analysis, which assesses the consistency of the questions with the construct being tested. where $\alpha \geq 0{,}9$ indicating excellent internal consistency; $0{,}8 \leq \alpha < 0{,}9$ good; $0{,}7 \leq \alpha < 0{,}8$ acceptable; $0{,}6 \leq \alpha < 0{,}7$ questionable; $0{,}5 \leq \alpha < 0{,}6$ deficient and $\alpha < 0{,}5$ inacceptable [28]. The coefficient α is calculated using equation (1):

$$a = \frac{N}{N-1}\left(1 - \frac{\Sigma\sigma^2}{\sigma_T^2}\right) \quad (1)$$

Where:
α: Cronbach's alpha (reliability value)
N: number of items
σ: variance of each item
σt: total variance

According to Joseph F., the sample size should be at least 5 times the number of variables analyzed [27]. Therefore, the variables analyzed were calculated using equation (2):

$$n \geq 5(k * c * r) \quad (2)$$

Where:
n: number of samples required
k: number of variables
c: number of categories
r: number of possible responses

The second stage consisted of quantifying BIM uses using survey data and descriptive statistical tools, such as the mean and coefficient of variation, as shown in equation (3).

$$\bar{x} = \frac{\sum x_i}{n} \quad (3)$$

Where:
xi: each of the values in the data set
n: total number of values

The third stage consisted of advanced statistical analysis using three techniques. First, the relative influence index (RII) was calculated using equation (4). The next step was an advanced nonparametric analysis (Kruskal-Wallis) to compare more than three independent groups [29], using equation (5). These equations are shown below:

$$RII = \frac{\Sigma(\omega)}{A * N} \quad (4)$$

Where:
ω: score given to each item by respondents
A: maximum possible score
N: total number of items

$$H = \frac{12}{N(N+1)}\sum_{i=1}^{k}\frac{R_i^2}{n_i} - 3(N+1) \quad (5)$$

Where
H: Kruskal-Wallis statistic
N: Total number of observations
K: Number of groups
Ri : Sum of the ranks of group i
Ni: Size of group i

Finally, the multiple correspondence analysis (MCA) was performed in SPSS to analyze relationships among variables and detect patterns or associations among the evaluated items [27]. For this purpose, data from a structured survey comprising 15 questions were used. The first six questions sought information about the respondent. The first question was about accepting the survey. The second question sought to establish the individual's profession. The third question sought to establish the individual's level of education. The fourth question sought to establish the respondent's years of experience. The fifth question sought to establish whether the professional had participated in road projects. The sixth question sought to determine their role in the project. The second part of the survey focused on evaluating BIM uses. Questions 7–9 evaluate the use of BIM for '3D modeling of existing and projected conditions' in relation to the three identified delay factors. Questions 10 to 12 focus on evaluating the use of BIM for 'interference analysis'. Finally, questions 13–15 evaluate the performance of BIM use for '4D planning'. These three BIM uses were evaluated in relation to the three identified delay factors. For the association, the normality test was first performed to ensure the reliability of the ACM. Then, the categories were grouped into the following: Average, impact level, experience, and role performed in projects. The categories were grouped into the following: Average impact level of the three BIM uses (five levels: very low, low, medium, high and very high impact); experience (four groups); and role performed in projects (five professions: resident, production engineer, quality engineer, supervisor, and assistant). This enabled multiple correspondence analyses to be performed. The MCA transformed the data table into a factorial space (a graph), where each point represents an evaluated variable.

III. RESULTS

This section presents the findings from the analysis of data collected during development. Cronbach's alpha analysis of the survey indicated high reliability (0.92). According to a survey of 73 people, 68 were validated, and 5 were removed because they did not meet the requirements. The first part aimed to gather information on respondents' professions, academic degrees, work experience, and participation in road projects. Of the respondents, 98.48% are civil engineers by profession, of whom only 33.33% have a master's degree, and 66.67% are graduates. Another aspect evaluated was the experience of the respondents, in which professional experience was divided into four groups: the first group with more than 15 years of experience represents 24.24%, followed by the group with 11-15 years of experience with 15.15%, the third with 5-10 years of experience representing 31.82%, and the fourth group with less than 5 years of experience representing 28.79%, as shown in Graph No. 1. Finally, another aspect evaluated was the role they played in their last road project, where it was highlighted that 40.91% of the respondents were site residents, 9.09% site supervisors, 13.64% were production engineers, 31.82% were technical assistants, and 4.55% were quality engineers.

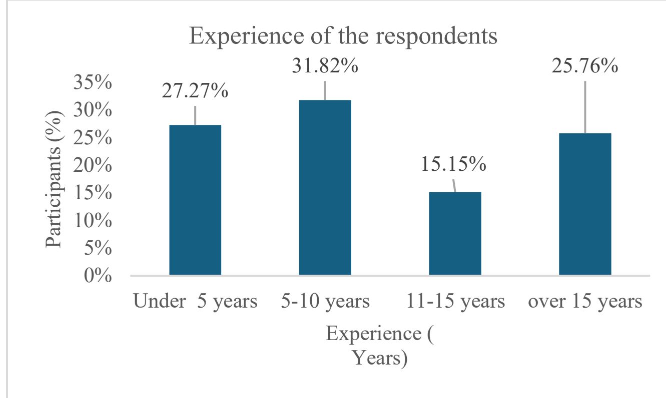

Fig. 1: Statistical table of respondents' experience

The second part of the survey focused on evaluating the impact of BIM uses on the main factors causing delays during construction, where three BIM uses were evaluated through nine questions, which are shown in the following graph, highlighting that the use of BIM for interference analysis to avoid changes during the design phase had a very high impact for 51.52% of respondents, as reflected in question P-9, while only 16.67% of respondents concluded that interference analysis has a medium impact on improving and controlling planning, as reflected in question P-9.

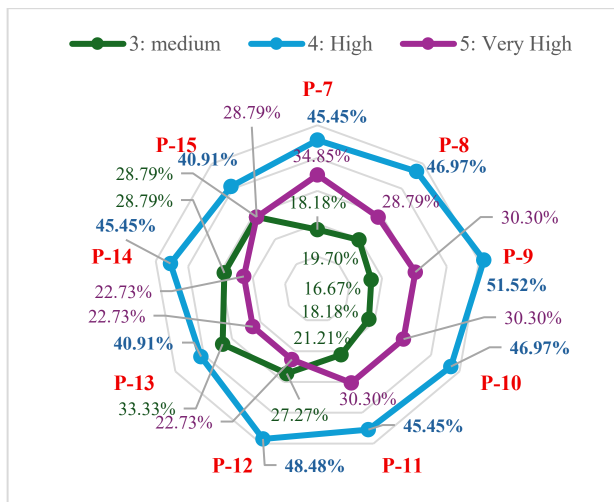

Fig. 2: Summary of the impact of BIM use

The results of quantifying the impact of BIM use through the cross-impact matrix show that the BIM use with the greatest positive impact was 3D modeling of existing and projected conditions, as seen in Table 4, which shows two rating scales: the first on a scale of 1-5 and the second on a scale of 0-1. It can also be seen that the minimum score is 3.79 and the maximum is 4.06, indicating a positive impact of BIM use.

Table 5: BIM usage impact assessment matrix

	BIM USE		
Delay factors	**3D modeling of existing and projected conditions.**	**Interference analysis.**	**4D analysis and planning.**
Design changes during construction	4.05 (0.81)	3.98 (0.80)	3.79 (0.76)
Inaccurate measurement estimates	3.94 (0.79)	3.98 (0.80)	3.86 (0.77)
Lack of planning monitoring and control	4.06 (0.81)	3.79 (0.76)	3.92 (0.78)
Average	4.02 (0.80)	3.92 (0.78)	3.86 (0.77)

The results were divided into three categories based on the analyses. The first was the analysis of BIM uses using the relative influence index, where it was observed that for the BIM use "3D modeling of existing and projected conditions" related to questions 7, 8, and 9, an incidence factor of 0.80 was obtained as a maximum for monitoring and control of planning, which represents a high degree of priority for this BIM use to improve planning monitoring and control, as can be seen in Fig. 3. In contrast, it was also observed that the BIM use "4D analysis and planning" related to questions 13, 14, and 15 had a minimum index of 0.74, indicating that although it is the lowest, it is still important.

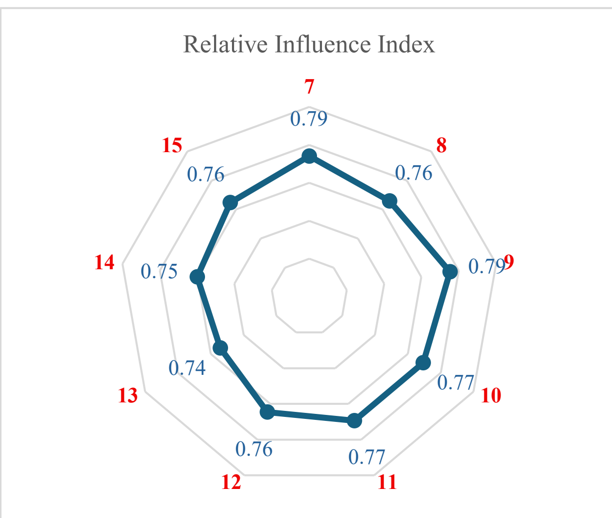

Fig. 3: Relative Influence Index

The BIM usage impact matrix (Table 5) reveals that 3D modeling of existing and projected conditions achieved the highest average score (4.02), outperforming interference analysis (3.92) and 4D planning (3.86). These suggest that in the context of Arequipa's Road projects, 3D modeling is perceived as the most effective tool for mitigating delays, particularly those related to planning, monitoring, and control (score: 4.06). Its ability to visualize spatial conditions and integrate design elements appears to enhance coordination and reduce ambiguity, which is critical in environments where planning deficiencies are prevalent. The interference analysis received strong ratings for minimizing design changes (3.98) and improving measurement accuracy (3.98), underscoring its preventive value for early-stage conflict detection. Compared with Pérez et al. [16], who reported an interference analysis impact score of 0.55, the higher rating in this study (0.78) may reflect the acute need for design stability in Arequipa's infrastructure projects.

Meanwhile, 4D planning, though slightly lower in average score, showed notable strength in improving time management (3.92), aligning with findings from Castañeda et al. [3], who emphasized its strategic role in scheduling. The consistency of the standard deviations (0.76–0.81) across all BIM uses indicates stable perceptions among respondents, reinforcing the data's reliability. Collectively, these results validate the differentiated utility of BIM applications and highlight the contextual priorities of road construction professionals in Arequipa, where visual clarity and early conflict resolution are paramount (Table 5).

Table 6: Results of the Kruskal-Wallis test

Test statistics [a,b]	
	Mean
Kruskal-Wallis H	2,870
G L	3
Asymptotic Sig	0,412
a. Kruskal-Wallis test	
b. Grouping variable: Experience	

Table 7: Kruskal-Wallis test results by professional role

Variable evaluated	**H**	**P-Value**	**Significant differences**
Impact on Planning	12.47	0.014	Yes
Impact on coordination	15.82	0.007	Yes
Impact on reducing delays	9.33	0.052	No

Table 8: Comparison's post-hoc Dunn

Comparison	P-Value	Interpretation
Supervisor vs. Residents	0.009	Supervisors perceive a greater impact
Engineers vs. Residents	0.031	Engineers perceive a greater impact
Engineers vs Consulting	> 0.05	No difference

The Kruskal–Wallis test revealed significant differences between professional roles in the perceived impact of BIM on planning (H = 12.47, p = 0.014) and coordination (H = 15.82, p = 0.007), as shown in Table 6. Post hoc Dunn comparisons (Table 7) indicated that supervisors and engineers reported significantly higher impact levels than resident engineers, while medians by group (Table 8) confirmed that residents consistently reported the lowest perceived impact. These univariate results suggest that BIM perception varies systematically across hierarchical and functional roles. Takyi-Annan 2023 Bryde [26], D., Broquetas, M., & Volm, J. M. (2013) [30].

The multiple correspondence analysis (MCA) in Figure 4 reveals distinct associations between professional roles, experience levels, and the perceived impact of BIM use. Professionals with over 15 years of experience, particularly resident engineers, are closely aligned with high and very high impact ratings, suggesting that those with extensive field exposure and decision-making authority recognize BIM's strategic value in mitigating delays and improving coordination. In contrast, respondents with less than 5 years of experience—often in support roles such as project assistants or quality control engineers—tended to receive lower impact ratings. This divergence highlights a potential gap in BIM training and integration across hierarchical levels. Mid-career professionals, including site supervisors and those with 5–10 years of experience, clustered around medium impact perceptions, indicating partial adoption or limited access to BIM tools. These findings underscore the importance of role-specific BIM engagement strategies: while senior staff may drive implementation, broader impact requires inclusive training and workflow integration. The MCA thus confirms that perceived BIM effectiveness is not uniform but is shaped by professional context, reinforcing the need for targeted capacity-building to maximize BIM's benefits in road infrastructure projects.

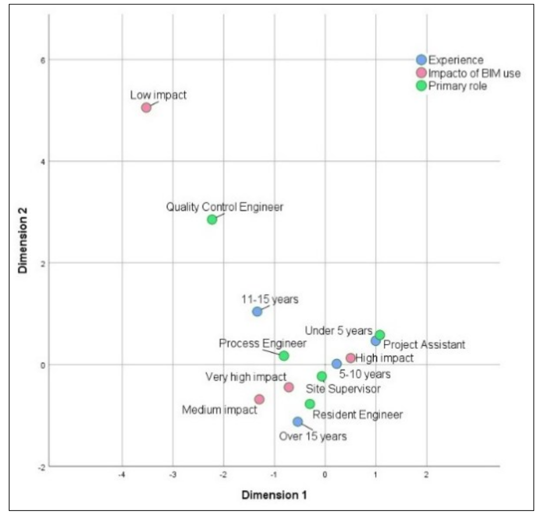

Fig. 4: Results of multiple correspondence analysis

IV. DISCUSSIONS

This section analyzed the results in relation to existing research. Pérez et al. [16] reported that 84% of the professionals surveyed had more than five years of experience, whereas this study found that 71.21% of respondents had a similar level of experience in road projects, supporting the reliability of the information provided. The concentration of experienced professionals also indicates that BIM perceptions in this study reflect practices shaped by traditional planning systems, offering a realistic view of the sector's current BIM maturity. The absence of significant differences in the Kruskal–Wallis test for experience groups reinforces this interpretation, suggesting that BIM adoption remains at a similar developmental stage across experience levels. This pattern aligns with recent findings by Castañeda et al. (2025) [3], who observed that BIM implementation in Latin American road projects remains concentrated in operational uses rather than in fully integrated workflows, reflecting an early-to-intermediate maturity stage across the region.

Overall, BIM applications clearly improve road project performance. However, future research should complement survey-based evaluations with case studies that enable data storage and AI-driven analysis. Expanding the set of delay factors and extending research to other areas of the construction sector will provide a more comprehensive understanding of BIM's benefits.

Regarding BIM uses, 3D modeling of existing and projected conditions obtained a rating of 0.80 in this study. Unlike Pérez et al., Castañeda [3] did not evaluate this use, despite its relevance in earlier work. Its inclusion here is significant, as the national context of Arequipa, Peru, differs from that of other regions, making this the first study to assess its application in local road projects.

The use of Interference Analysis received a rating of 0.78, reflecting its capacity to anticipate and resolve conflicts early, thereby supporting timely project delivery. In contrast, Pérez et al. [16] reported a lower rating of 0.55, likely due to differences in project characteristics.

For 4D analysis and planning, Castañeda [3] reported a rating of 0.84, while this study obtained 0.78. Although slightly lower, the result confirms the benefits of 4D analysis, particularly in enhancing time management through integration with 3D models. The results also provide insight into the current level of BIM maturity in the road construction sector of Arequipa, suggesting an early-to-intermediate level of development. The strong impact attributed to 3D modeling and interference analysis indicates that BIM is being used primarily as a technical tool to enhance visualization and detect conflicts an adoption pattern consistent with the early operational focus described in regional studies.

Finally, the application of ACM revealed strong associations between professional experience, project role, and the perceived impact of BIM use. The degree of association (0.000–0.02) underscores that the role played within the project significantly influences the impact of BIM. This constitutes the first study to analyze such associations in road projects, reinforcing its innovative contribution.

V. CONCLUSIONS

The impact of BIM use on road construction projects in Arequipa was consistently positive. Among the evaluated applications, 3D modeling of existing and projected conditions showed the greatest influence, achieving the highest average score (4.02) and the highest Relative Influence Index coefficient (0.79). All BIM uses obtained scores above 3.79, confirming that interference analysis and 4D planning also contribute meaningfully to mitigating the main delay factors, particularly design changes, measurement inaccuracies, and deficiencies in planning and control.

The statistical analyses reinforce these findings. The Kruskal–Wallis test revealed no significant differences across experience groups, indicating that perceptions of BIM's usefulness are relatively stable regardless of years of practice. However, strong associations were identified between professional roles and perceived impact, with supervisors and engineers reporting higher benefits than resident engineers. The MCA confirmed these role-based patterns, suggesting that BIM effectiveness is shaped not only by technical capacity but also by the responsibilities and decision-making authority associated with each role.

Taken together, the results indicate that BIM adoption in Arequipa's road sector corresponds to an early-to-intermediate maturity stage. The strong performance of operational uses such as 3D modeling and interference detection, combined with the comparatively lower integration of 4D planning, reflects a regional pattern in which BIM is still transitioning from technical support functions toward more integrated planning and management workflows.

This study provides the first empirical evidence of BIM's impact on road construction projects in Arequipa and contributes to the broader understanding of BIM adoption in emerging contexts. Future research should incorporate case-based analyses, integrate objective performance metrics, and explore the use of digital traceability and AI-driven monitoring systems to support more advanced planning and decision-making capabilities.

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