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Consequences in cost and time in construction projects due to the low level of BIM methodology use

Consecuencias en el costo y plazo de proyectos de construcción debido al bajo nivel de uso de la metodología BIM

*Rivera, A. * https://orcid.org/0000-0003-3887-0389*
*Saigua, S. * https://orcid.org/0000-0002-8378-3367*
*Castillo T. * https://orcid.org/0000-0002-3472-3456*
*Andrade A. *, ** [1]https://orcid.org/0000-0003-1543-4381*
Zárate, A. https://orcid.org/0000-0002-7183-2862*

* Universidad Nacional de Chimborazo, Riobamba, Ecuador
** Universidad Politécnica de Valencia, Valencia, España

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Abstract
BIM (Building Information Modeling) methodology has established itself as an essential tool in the construction industry. Despite this, in Ecuador, the use of BIM is lagging, and although there are some initiatives in private companies, its use is still limited. The purpose of this research is to identify the consequences of cost and time in construction projects due to the low level of use of BIM methodology in 30 projects of private companies in Ecuador. To achieve this, the BUA (BIM Use Assessment) tool was used to evaluate the level of BIM use in each project during the planning and design phases. Subsequently, cost and schedule data were collected for the evaluated projects. The results show that the main consequences of the low level of BIM usage are associated with the increase in cost and schedule. It is concluded that promoting the use of BIM is essential to improve the performance of the construction industry in Ecuador.

Keywords: *BIM; BIM usage level; consequences; costs; time of execution*

Resumen
La metodología BIM (Building Information Modeling) se ha establecido como una herramienta esencial en la industria de la construcción. A pesar de esto, en Ecuador el uso de BIM está rezagado, y aunque existen algunas iniciativas en empresas privadas, su uso aún es limitado. El propósito de esta investigación es identificar las consecuencias en el costo y el plazo de proyectos de construcción debido al bajo nivel de uso de la metodología BIM en 30 proyectos de empresas privadas en Ecuador. Para lograr esto, se utilizó la herramienta BUA (BIM Use Assessment) para evaluar el nivel de uso de BIM en cada proyecto durante las fases de planificación y diseño. Posteriormente, se recopilaron datos de costo y cronograma para los proyectos evaluados. Los resultados muestran que las principales consecuencias del bajo nivel de uso de BIM están asociadas con el aumento de costos y plazos. Se concluye que promover el uso de BIM es esencial para mejorar el desempeño de la industria de la construcción en Ecuador.

Palabras clave: BIM; nivel de uso de BIM; consecuencias; costos; tiempo de ejecución.

1 Corresponding author:
Universidad Nacional de Chimborazo, Riobamba, Ecuador
Corresponding author: alexis.andrade@unach.ec

1. Introduction

BIM (Building Information Modeling) methodology has been developed as a useful tool for improving the efficiency of construction projects. However, in Latin American countries the digitization processes in the AEC (Architecture, Engineering, and Construction) sector had a late start in comparison with more developed countries such as the United States or Canada (Benn, 2022) (EUBIM TaskGroup, 2017). Despite this, its momentum is allowing a rapid spread and use in construction, countries such as Chile and Brazil are the leaders in the effective and early use of BIM (Alvaro, 2023) (Sanabria, 2023).

On the other hand, in Ecuador, these technological tools have been incorporated gradually into the construction processes, but currently, there is a great delay in the use of BIM standards (Paguay and Reyes, 2020). The lack of resources for technological updating, the limited use of software, and resistance to change are several of the causes of the low level of BIM use, including the lack of a national standard and regulatory framework established by the government that is interfering with the proper advance of BIM development (Claudio and Salazar, 2022).

While it is recognized that these causes are the main obstacle for generating a transformation in the construction sector in Ecuador, it should be considered that this generates expenses due to increased costs and delays in delivery times (Charef, 2021) (Bué, 2020). Besides, (Azhar, 2011) established that the use of BIM reduces unbudgeted changes by up to 40% since it reduces the time necessary to generate a re-estimation of costs, generating savings of up to 10% of the contract value through conflict detections, and up to a 7% reduction in project time.

Therefore, this research aims to identify the consequences of cost and time in construction projects due to the low level of BIM methodology used in 30 projects of private companies in Ecuador. For this purpose, the use of BIM methodology in each of the projects was evaluated and, by obtaining cost and time data, it was aimed to identify the consequences of the low level of BIM use.

Providing a clearer vision of the current state of how construction processes are being carried out helps to avoid the mistakes of the past, which leads to the next steps towards the digital transformation, which requires establishing policies that encourage BIM use and allow the introduction of this new technology, as well as the training for the work team and having adequate tools (Salinas and Ulloa, 2014).

2. Level of BIM use

The low use of BIM methodology, not only in Ecuador but worldwide, has consequences that are reflected in the persistence of an increase in the estimated budget, delays in the execution deadlines of each stage of the project, higher presence of interferences and risks of conflicts during construction, which could lead to a decrease in the final quality of the project (Ramirez, 2018).

Rojas et al., (2019) provide the BIM Use Assessment (BUA) tool based on the measurement of 10 BIM uses developed during the planning and design phase, which are aligned with the project objectives, for every one of these BIM uses are defined characteristics and states needed for the project completion. BUA mainly focuses on design and planning since these activities are highly related to schedule and cost achievement when correctly developed in the early stages of the project. BUA was tested in the evaluation of BIM application in construction projects in Chile, Colombia, and Spain demonstrating reliability (Rojas et al., 2019).

The 10 uses of BIM, evaluated in BUA, are rated against a template that has a scale from 1 to 5, where level 1 refers to the use of traditional methods or absence of BIM use, level 5 refers to BIM being used completely, this rating proposal provides a properly structured tool which allows comparisons and rating of projects. A BIM use is a set of actions and conditions that are associated and have an objective or application defined for the construction project.

However, the BUA tool application is limited to the evaluation of the planning and design (Park et al., 2022). (Herrera et al., 2021) mentioned that there is a significant difference in the application of BIM depending on the content of the work, which may affect the validity of the tool. Despite these limitations, BUA provides a useful guideline to assess the level of BIM use in projects and can be used to identify areas for improvement. Also, BUA reduce the risk that the evaluation is affected by the confusion that most of the specialists have about the use of the software and the BIM methodology.

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3. Methodology

This research has a descriptive, comparative, and correlational scope since data were collected to establish the relationship between the level of BIM use with cost and schedule. In the descriptive scope, data were collected to describe its characteristics and properties. The comparative scope was performed between two or more variables to identify similarities and differences. Finally, in the correlational scope, the relationship between two or more variables was examined to determine if there is an association between them.

On the other hand, the research was divided into two phases. The first one was to identify private companies in Ecuador that have planned and designed construction projects using BIM. To obtain a broad and diverse sample, projects developed by companies in the main cities of Ecuador (Quito, Guayaquil, Cuenca, and Ambato), were considered as study subjects. A non-probabilistic sampling was used, and BUA was applied to 30 projects of 15 construction companies. To maintain privacy and confidentiality, the term project was used identified from 1 to 30. In the second phase, data about the estimated budget, final budget, planned execution schedule, and final execution schedule of the projects was collected. The purpose of this collection was to compare the projects that have a high level of BIM use with the projects that have a low level of use.

A database was created with BUA values, schedule, and cost data of the construction projects. To perform the correlation analysis, the Shapiro-Wilk test was initially carried out, in which it was determined that the averages of the levels of use did not follow a normal distribution; therefore, Spearman's correlation coefficient was used, since this test evaluates the relationship between two variables when at least one of them does not follow a normal distribution.

Aiming to analyze differences between BUA uses and data central tendency, box plot diagrams were used. Last, radar diagrams were used to compare the levels of BIM use of each project, classified as high use (levels 4 y 5) and low (levels 1, 2 and 3).

4. Results

4.1. Level of BIM use

After applying the BUA questionnaire, the projects were classified into two categories according to the level of use of the BIM methodology: high level (levels 4 and 5) and low level (levels 1, 2 and 3). An average level was obtained, as shown in (Figure 1).

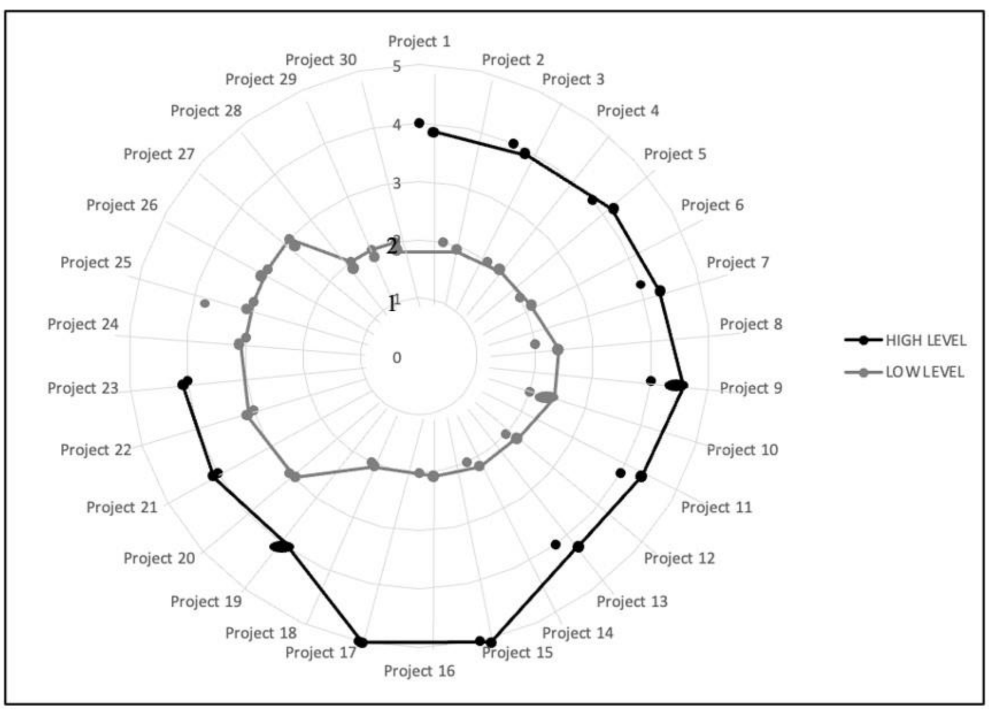

***Figure 1**. Projects with high and low levels of BIM use.*

The graph shows 12 projects located in the category of high level of BIM use, with level 4 being the most frequent, while only 2 projects were in level 5. It also shows the distribution of 18 projects with a low level of BIM use, of which 12 are in level 2 and only 6 in level 3.

4.1.1 Variation in levels of BIM uses

Box plots were used to represent the data obtained from BUA, since they allow us to visualize the distribution of a set of data, in this case, the levels in the 10 uses of BIM. The maximum, minimum value and median are presented to compare the level distribution and determine probable patterns of behavior.

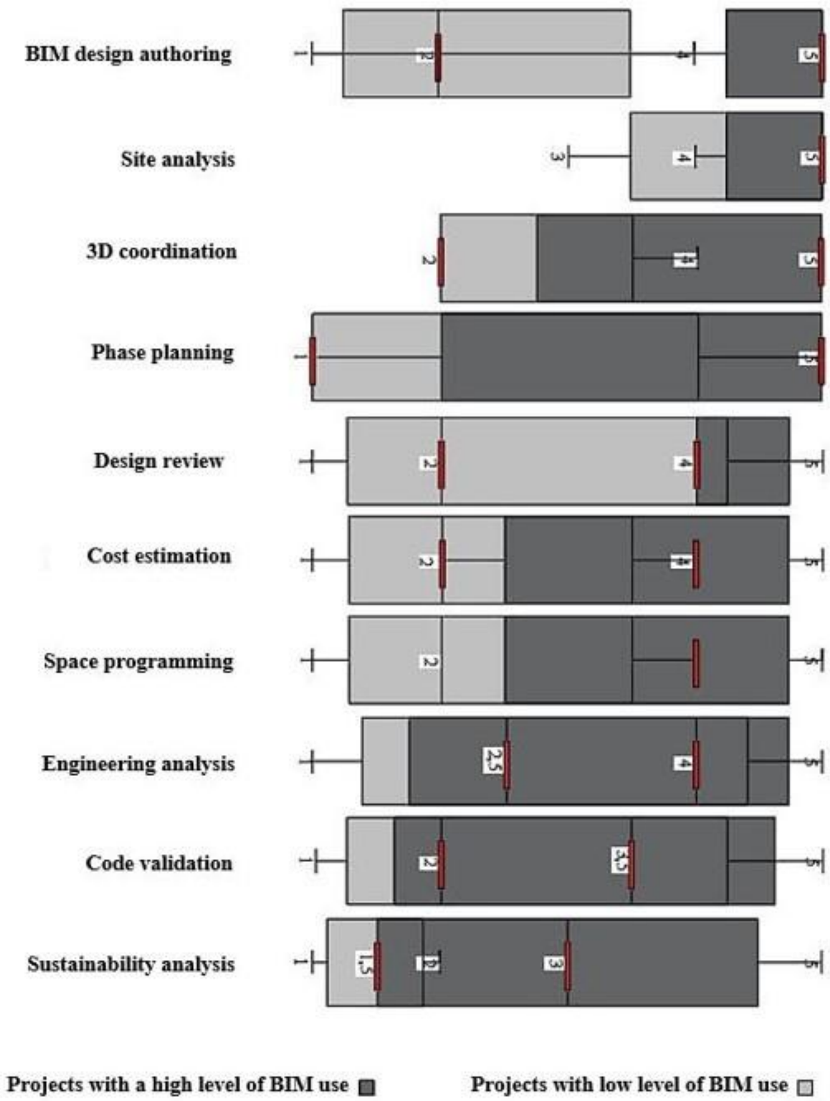

Figure 2. *Box plot of projects with high and low BIM usage levels.*

For high-level projects, level 5 was observed to be the highest in each of the uses, suggesting that BIM methodology has been effectively used. However, it was found that the lowest level was observed in engineering analysis, sustainability analysis, standard/code validation, and phase planning, indicating that only 2D models were used. One of the major deficiencies in projects with high levels of use is the sustainability analysis, understanding that this analysis can identify risks and economic possibilities for the project, in addition to improving resource management. Another aspect that is also affecting is the validation of code and standards, as they can generate additional costs such as fines for non-compliance and delays due to construction supervision or readjustments in the construction plan.

In the low-level projects, it was found that due to the lack of use of software compatible with BIM methodology and the use of 2D and 3D models by untrained personnel, hence the lowest levels identified were 1, 2, and 3. In conclusion, most of the projects analyzed do not make effective use of BIM models, as shown in (Figure 2). The major deficiency shown in low-level projects is the planning phase, which leads to a lack of proper organization and project follow-up, as well as a deficient allocation of resources, causing them to be fully utilized in the early stages. Likewise, cost estimation is a critical aspect that has a great impact on budget mismanagement, and it is fundamental for financial control.

4.2 Cost and time analysis

To achieve a more efficient performance of the research, data were collected on the estimated budget, final budget, planned execution time, and final execution time of the 30 projects evaluated. On the other hand, a percentage variation of both cost and time is essential to analyze the influence of the level of BIM use on costs and time.

***Table 1**. Summary of cost and time variation of the projects*

Project	BIM Use	Cost Variation	Schedule Variation
Project 1	4	-33.87%	67.03%
Project 2	4	-57.38%	-33.70%
Project 3	4	-8.27%	-16.48%
Project 4	4	0.00%	0.00%
Project 5	4	0.00%	0.00%
Project 6	4	-22.00%	16.48%
Project 7	4	7.00%	50.00%
Project 8	5	0.00%	0.00%
Project 9	5	0.00%	0.00%
Project 10	4	5.00%	5.02%
Project 11	4	5.00%	4.92%
Project 12	4	2.00%	12.60%
Project 13	2	15.21%	75.41%
Project 14	2	27.52%	10.52%
Project 15	2	28.09%	-29.84%
Project 16	2	20.63%	-25.00%
Project 17	2	18.02%	-15.56%
Project 18	2	-2.07%	7.58%
Project 19	2	32.98%	25.14%
Project 20	2	67.86%	100.00%
Project 21	2	21.01%	8.22%
Project 22	3	-6.76%	12.30%
Project 23	3	4.72%	19.61%
Project 24	3	21.95%	17.65%
Project 25	3	17.65%	13.60%
Project 25	3	14.94%	100.44%
Project 27	3	15.00%	66.67%
Project 28	2	30.00%	30.56%
Project 29	2	24.89%	15.07%
Project 30	2	29.87%	18.93%

In (Table 1) the negative percentages in cost variation indicate savings generated by the use BIM, while positive percentages represent an increase in cost. Projects that used BIM at all stages had a 0% cost variation. In projects S1, S2, SD1, and W2 the calculations were performed manually because were an intermediate value, but BIM was used during construction and these costs were recalculated with BIM methodology which generated savings that are reflected in the variation percentage. Projects T1 and W1 also used traditional calculations and then recalculated with the BIM methodology, showing a decrease in costs, although it is minimal. In the remaining projects, despite the use of BIM, an increase in cost can be noted due to deficiencies in applications, and in several projects, the estimation of quantities and costs was not generated with 3D models and integrated software automatically.

On the contrary, in the schedule analysis, the negative values indicate a decrease in time, while the positive percentages represent an increase in time. The projects that do not present variations used BIM in each of the stages. In projects S1, S2, SD1, and W2, although they were planned traditionally and later recalculated with the BIM methodology, only projects S2 and SD1 managed to decrease the time frame. In the rest of the projects, there is a significant variation in the deadlines due to the deficiency in the use of BIM and the lack of use of 4D models for effective planning, however, it is important to note that several projects had delays due to COVID-19.

4.3 Correlational analysis of the level of BIM use with cost and schedule

The test applied for the level of BIM methodology usage and the variation in project cost indicates that there is a moderately strong inverse correlation, i.e., as the level of BIM usage increases the variation in cost is expected to decrease. The significance value (p) being <0.001 shows that this correlation is statistically significant, suggesting that the probability of this relationship occurring by chance is very low. Consequently, it can be inferred that the correct use of the BIM methodology could be associated with greater efficiency and cost control in projects.

On the other hand, the analysis of the level of BIM methodology uses and the variation in project schedules shows that it indicates a weak inverse correlation, which shows that as the level of BIM use increases the variation in schedule is expected to decrease, however, it is not possible to make a strong statement about the relationship of the variables. The significance value (p) being 0.215 indicates that this correlation is not statistically significant.

To obtain a more accurate correlation analysis, scatter plots were used to determine the possible relationship between the level of BIM use with cost and schedule. The inclusion of these graphs allowed us to obtain relevant information on the effectiveness of BIM adoption in the evaluated projects, which could suggest improvements in its use. Since the objective of the research is to determine the consequences of the low BIM methodology usage, it was decided to perform an analysis of the percentage of variation of projects with a high level of use, projects with a low level and finally projects that initially use a traditional methodology and then were recalculated with BIM, in this way we can appreciate more precisely how the adoption of BIM influences.

Finally, to obtain a general analysis of the percentage of variation of both variables, the medians were used as a measure of central tendency, because the data set does not follow a normal distribution, therefore, the medians are less sensitive to extreme values or outliers.

Correlation of the cost of projects with high-level

The data obtained from the correlation ($\rho = -0.541$, $p = 0.167$, $N = 8$) between the level of BIM use and the cost of 8 projects with a high level, show that, according to the correlation coefficient (ρ), there is a medium inverse relationship and the significance value (p) suggests that there is not enough evidence to reject the alternative hypothesis, which in this case is that the cost does have a relationship with the level of BIM. In other words, as the use of BIM in projects increases, costs tend to decrease. The percentage analysis showed that using BIM at a higher level can result in a 1% difference in costs.

Correlation of the cost of projects with low-level

In the correlation ($\rho = -0.658$, $p = 0.006$, $N = 16$) between the level of BIM usage and the cost of 16 projects with a low level, it can be inferred that there is a considerable inverse relationship, and the null hypothesis is rejected. This means that as the level of BIM decreases, project costs tend to increase. In the percentage analysis, it was determined that using BIM at a lower level results in a 21.48% difference in costs.

Correlation of the cost of projects with traditional methodology and recalculated with BIM.

The correlation ($\rho = -0.845$, $p = 0.034$, $N = 6$) between the level of BIM usage and the cost of 6 projects that were initially performed with a traditional methodology and subsequently recalculated with BIM, shows that, there is a very strong inverse relationship and that the null hypothesis is rejected. This means that as the BIM methodology is used, project costs tend to decrease. The percentage analysis showed that by using BIM, costs can be reduced by approximately 15.13%.

Correlation of the time frame of high-level projects.

For the correlation ($\rho = -0.523$, $p = 0.227$, $N = 7$) between the level of BIM use and the deadline of 7 projects with a high level, only 7 were analyzed, since project SE1 had a delay due to COVID-19, which prevents these data from reflecting the normal influence of BIM.

The data show us that there is a mean inverse relationship and that there is insufficient evidence to reject the alternative hypothesis, which in this case shows that the project schedule does have a relationship with the level of BIM. In other words, as the level of BIM increases, project schedules tend to decrease. The percentage analysis showed that the use *of BIM at a higher level can result in a 0% difference in lead time.*

Correlation of time frame of low-level projects.

The correlation data (ρ = 0.307, p = 0.247, N = 16) between the level of BIM usage and the time frame of 16 projects with a low level, show that there is a positive average relationship and insufficient evidence to reject the alternative hypothesis. That is, as the level of BIM increases, project timeframes tend to decrease. However, it should be noted that the graph shows a positive slope, which suggests that the time should increase, nevertheless, there may be other factors that influence the deadlines, these may be the location of the project, climate, and labor, among others. In the percentage analysis it was determined that, when using BIM at a lower level, a difference of 18.29% is obtained in timeframes.

Correlation of the time frame of projects with traditional methodology and recalculated with BIM.

For the correlation (ρ = -0.224, p = 0.718, N = 5) between the level of BIM use and the schedule of 5 projects that were initially performed with a traditional methodology and later recalculated with BIM only 5 projects were analyzed since project S1 had a delay due to COVID-19.

The data show us that there is a negative average relationship, and that the alternative hypothesis is rejected, however, there is insufficient evidence. That is, as the BIM methodology is used, project schedules tend to decrease. In the percentage analysis, it was obtained that, by using BIM, timeframes can be reduced by approximately 7.58%.

4.4 Cause and effect analysis

The linear regression technique was used to establish the cost and time consequences of the low level of BIM methodology use (Table 2).

Table 2. *Summary of linear regression test data for cost with SPSS*

Summary of the model

Model	R	R squared	R squared adjusted	Standard error of the estimate
1	0.653[a]	0.426	0.405	17.4732

a. Predictors: (Constant), Levels

ANOVA[a]

Model		Sum of squares	gl	Quadratic mean	F	Sig.
1	Regression	6339.426	1	6339.426	20.764	<0.001[b]
	Residue	8548.752	28	305.313		
	Total	14888.179	29			

a. Dependent Variables: Cost variation
b. Predictors: (Constant), Levels

Coeficients[a]

Model		Non-standardized coefficients		Standardized coefficients	t	Sig.
		B	Desv. Error	Beta		
1	(Constant)	53.978	10.311		5.235	0.000
	Levels	-14.569	3.197	-0.653	-4.557	0.000

a. Dependent variable: Cost variation

The results of the cost variation percentage analysis suggest that there is a moderate correlation between the two variables, suggesting that the low level of BIM is related to increased cost. However, it is not only the level of BIM usage that should be considered, as other factors affect costs, and certain uncertainties in forecasts based on this criterion should also be anticipated (Table 3).

Table 3. *Summary of linear regression test data for timeframe with SPSS*

Summary of the model				
Model	R	R squared	R squared adjusted	Standard error of the estimate
1	0.151[a]	0.023	-0.012	34.40937

a. Predictors: (Constant), Levels

ANOVA[a]						
Model		Sum of squares	gl	Quadratic mean	F	Sig.
1	Regression	776.676	1	776.676	0.656	0.425[b]
	Residue	33152.129	28	1184.005		
	Total	33928.804	29			

a. Dependent Variables: Time variation
b. Predictors: (Constant), Levels

Coeficientes[a]						
Model		Non-standardized coefficients		Standardized coefficients	t	Sig.
		B	Desv. Error	Beta		
1	(Constant)	34.211	20.305		1.685	0.103
	Levels	-5.099	6.296	-0.151	-0.810	0.425

a. Dependent variable: Time variation

The schedule analysis shows that there is a very weak and almost null relationship between these two variables, this indicates that the variability of the schedule cannot be explained to a large extent by the level of BIM usage. Therefore, it is possible that there are other factors that influence the project timeframe, in this case, COVID-19 was identified as a significant factor.

5. Discussion

According to the results obtained with BUA, there is a clear difference in the levels of BIM use in high-level and low-level projects. In high-level projects, there is greater use in 3D coordination, BIM design development, design review, engineering analysis, site analysis, phase planning, and cost estimation. This shows that Ecuadorian companies have made significant progress in the adoption of this methodology in recent years, in contrast, the research by (Arellano et al., 2021) showed that the projects evaluated remained at levels 1, 2, and 3 in the uses mentioned above.

Despite the current use of BIM in Ecuador, there are still deficiencies in its use, since uses such as sustainability analysis, code/regulation variation and spatial programming maintain a level 3 in high-use projects, this is mainly due to the lack of qualified personnel and the lack of application of appropriate software. The main causes of these deficiencies as mentioned by (Claudio and Salazar, 2022) are the lack of resources for the use and updating of technological tools, the preference for traditional methodology, and the lack of training of the work team and national standards.

On the other hand, the analysis of the cost and time variation percentages showed that projects with a high use of BIM have a lower cost and time variation, because they use most of the benefits that come with the use of BIM models and project automation, allowing to share information between different departments, correcting errors and identifying interferences before the start of construction. As mentioned by (Sarvari et al., 2020) the use of BIM is constantly growing in different countries around the world, due to its ability to exert a significant influence on time, cost, and quality objectives during all phases of the life cycle of a construction project, that is confirmed by the findings of the present research.

In contrast, the use of traditional methodologies involving 2D and 3D models brings an increase in the estimated budget and time delays, as shown in the projects with low usage, where a clear increase in the percentage of variation was observed. This study confirms the negative consequences of low BIM usage, which are supported by the research conducted by (Ramirez, 2018). According to this author, low BIM use can lead to increased costs, delays in the execution of deadlines, increased presence of errors, and risks of conflicts during construction.

The adoption and proper use of BIM in a project require a series of practices and skills that allow for improving efficiency, accuracy, and coordination in the construction process, consequently, the evaluated projects show an approximate reduction of 15.13% in costs and 7.58% of deadlines, compared to projects using traditional methodologies, agreeing with (Azhar, 2021).

6. Conclusions

After evaluating the 30 construction projects, it can be concluded that the low level of BIM use brings consequences that are directly related to the increase of the final budget and the delay of the execution deadline, since, it should be understood that BIM is a methodology that helps the efficiency and quality of the projects, especially in the cost and deadline management.

The application of BUA allowed classification of the projects according to their high level and low level of use, in which only 12 projects obtained a high level, and the remaining 18 projects were located at a low level; this result is mainly due to the lack of training and knowledge, which is a critical factor that limits its adoption. It is evident that in Ecuador there is still a limited use of this methodology since its use is partial in several uses of BIM.

It has been determined that a high level of BIM use allows a difference of 0% to 2% in costs and 0% to 1% in deadlines, since projects with a high-level present variation, but the final value partially deviates from the planned value. On the contrary, projects with a low level of BIM use present an increase in costs and a delay in execution time due to errors and conflicts that arise during the construction process, thus allowing a difference of 21% to 22% in costs and 17% to 19% in time. Finally, it can be concluded that higher use of BIM is related to a 15% cost reduction and 8% deadline reduction, compared to the use of traditional methodologies. It is important to note that these results are based on a limited sample and more studies are needed to confirm these conclusions.

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