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BIM Methodology and Montecarlo Analysis as Mitigation Tools of Construction Cost Overrun

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***Abstract* -** Construction project management frequently encounters significant cost control challenges, with cost overruns being among the most persistent and critical issues. This paper proposes a risk management method for multifamily housing projects that integrates BIM methodology with Monte Carlo analysis. This combination enables a detailed visual and quantitative assessment, facilitating risk identification and quantification, and providing precise cost control. Through comprehensive analysis, including literature reviews, case studies, and surveys of construction experts-the primary risk factors contributing to cost overruns were identified, such as design errors and cost estimation issues. Results indicate that the combined use of BIM and Monte Carlo enhances resource planning and minimizes cost overruns. Validation surveys demonstrate considerable acceptance of this method among professionals, who recognize its effectiveness and applicability in risk management for multifamily projects.

***Keywords*:** Project, Risk management, cost overrun, BIM, Montecarlo analysis.

1. Introduction

Construction project management is constantly facing challenges related to cost control, where cost overruns are one of the most persistent and critical problems worldwide. Recent studies show that approximately 90% of construction projects experience significant cost overruns, with average budget deviations of up to 28% [1]. This phenomenon is exacerbated by the presence of inherent risks in all phases of the project, negatively impacting budgets. This problem is especially relevant in multi-family projects, where housing demand has driven a growth in construction, increasing complexity and the risk of cost deviations. The importance of addressing this issue is that cost overruns not only affect the profitability of projects, but also the affordability of housing in high-demand urban areas, compromising urban development and efficient planning.

Over the years, studies have addressed the causes and mitigation strategies for cost overruns in construction, revealing the complexity of these factors and their solutions. Previous research has identified that cost overruns often originate from factors such as poor planning, schedule delays and design changes [2],[3]. In terms of mitigation, methodologies have been proposed to reduce these cost overruns, most notably appropriate planning and collaboration [4] and the use of approaches such as system dynamics in less developed contexts [5]. Earned Value Management and Monte Carlo analysis are presented as effective tools for more accurate risk assessment, allowing control over cost and time [6]. More recently, a methodology combining earned value analysis with risk management tools has been proposed, leading to a decrease in cost overruns and increased customer satisfaction.[7] In addition, the use of Monte Carlo analysis and Monte Carlo analysis has been proposed as an effective tool for more accurate risk assessment, allowing control over cost and time [7].

In this context, the proposal of this article focuses on the development of a risk management system specifically for multifamily projects. This system integrates BIM methodology and Monte Carlo analysis, combining their strengths for a more robust risk assessment and control. The use of BIM facilitates a detailed and dynamic visualisation of each project phase and component, which in turn aids in risk identification and proper resource planning [8]. In addition, this technology improves communication and collaboration between the various stakeholders involved, which is crucial in such a dynamic environment [9].

On the other hand, Monte Carlo analysis provides a quantitative approach to simulate the financial impacts of identified risks, allowing project managers to anticipate critical scenarios and make informed decisions based on concrete data [10].

Through this combination of tools, the study aims to optimise risk management and contribute to the sustainability of the sector.

This article aims to demonstrate the advantages of integrating BIM methodology with Monte Carlo analysis for cost overrun minimisation in construction projects. By combining these tools, the aim is to provide a quantitative and visually detailed approach that allows project managers to anticipate financial risks and improve resource planning. This integration not only optimises cost estimation accuracy, but also facilitates informed decision making, promoting the sustainability and efficiency of construction projects.

2. Materials and Tools

The research is based on a series of tools and materials that allowed for a detailed analysis of the causes of cost overruns and the effectiveness of various management methodologies in construction projects. These key elements are described below:

Literature Review: Grouped into causes of cost overruns, mitigation measures, and management methodologies, academic articles provided critical insights for analysis.

Revit Software: Used for BIM modelling to detect design issues, provide accurate cost estimates, and optimize planning, reducing cost overruns through better resource management.

Monte Carlo Simulation: Applied to evaluate risk impacts on costs and timelines, generating scenarios to inform decision-making under uncertainty.

@Risk Software: Enabled advanced Monte Carlo simulations to assess variable impacts on costs and schedules, supporting contingency allocation and decision-making.

CPM and PERT: These probabilistic methods offered detailed insights into project timelines and costs, facilitating effective planning and deviation anticipation.

Reference Class Forecasting (RCF**):** Enhanced financial estimations and contingency allocation, reducing financial risks.

Surveys of Professionals: Collected data on risk frequency, impact, and management practices, enriching the understanding of critical factors in construction risk management.

3. Method and/or Methodology

3.1 Identification and Analysis of Main Risks

To identify the main risks causing cost overruns, the method comprised two phases: a literature review and structured surveys. The literature review highlighted key risks such as planning issues, inaccurate cost estimates, and scope changes, focusing on recent high-impact publications to ensure relevance. Surveys were conducted with 30 experienced civil engineers working on multi-family projects in Peru. Participants, with a minimum of 3 years' experience (mostly 10–20 years), provided insights on risk frequency, impact, and management practices based on their involvement in over five projects.

Additionally, three multi-family projects in Lima were selected based on their structured management and risk practices. In-depth interviews with resident engineers examined tools (e.g., BIM, MS Project) and methodologies for risk management. A comparative analysis of the cases revealed strengths, areas for improvement, and common practices, evaluating the influence of risk management on project performance.

3.2 Development of the Proposed Risk Management Model

Based on the findings, a new risk management model was proposed by integrating BIM and Monte Carlo simulation. One of the case study projects was selected for detailed analysis. BIM modelling of the foundation stage in Revit provided an accurate representation of elements, costs, and dimensions, forming the basis for risk simulations. Using Monte Carlo analysis, risks were quantified with probability distributions, generating scenarios of cost variation. Software parameters were calibrated for accuracy, and protocols were documented to ensure replicability.

The comparative analysis of the three projects helped identify effective practices and gaps in quantitative risk analysis. These findings informed the design of an improved method that combines BIM's modelling capabilities with Monte Carlo's probabilistic analysis, enhancing cost control and supporting decision-making.

3.3 Application and Validation of the Model

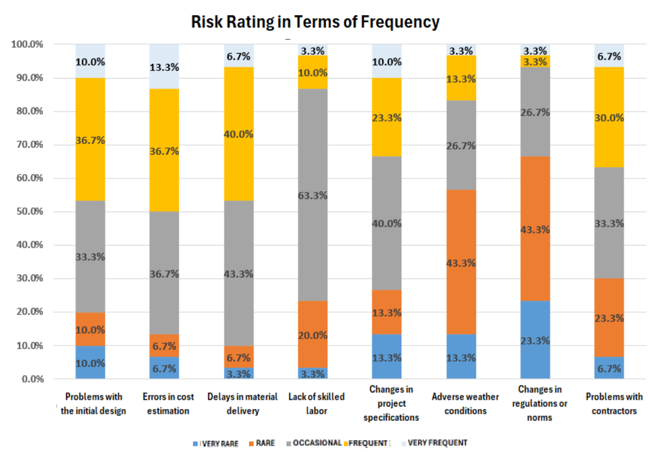
The proposed method was applied to a selected case study, combining BIM for cost management and Monte Carlo for for risk simulation. Results, compared to conventional practices, demonstrated improved cost predictions and control. Expert Expert feedback validated the model's advantages, emphasizing its potential to reduce uncertainties and optimize resource resource allocation.

4. Results

4.1. Risk Identification

For the first stage, based on a literature review and surveys of civil engineers with experience in multifamily projects, the most common risks affecting costs in these projects were identified. Among them, the following stand out: Errors in the initial design, inaccuracies in cost estimation, delays in the supply of materials, insufficiency of skilled labour, changes in project specifications, adverse weather conditions, regulatory changes and problems with contractors.

For the second stage, surveys were conducted among professionals with experience in the construction sector. To analyse the risks in more detail, the respondents evaluated the eight risks in terms of frequency and impact. The risks were classified into five levels of frequency: very rare, rare, occasional, frequent and very frequent. The results, shown in Figures 1 and 2, indicated that the risks with the highest frequency and greatest impact were:



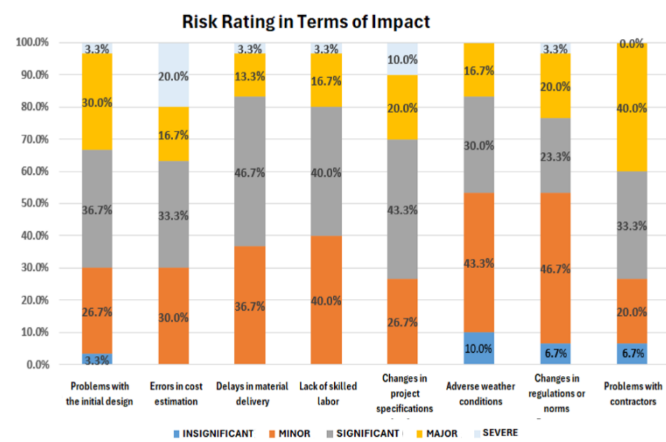


Fig. 1. Rating risks in terms of frequency   Fig. 2. Rating of risks in terms of impact

The most significant risks in the projects analysed were identified as cost estimation errors, problems with the initial design and problems with contractors. Cost estimation errors were considered frequent by 50% of respondents, and 36.7% rated their impact as high severity. Problems with the initial design had a frequency of 46.7%, with a high severity impact according to 33.3% of respondents. Finally, although problems with contractors had a lower frequency (36.7%), 40% of respondents rated their impact as highly serious.

4.2. Analysis of risk management development in case studies

Of the three case studies analysed, key aspects of risk management were assessed, including the tools used, the approach to risk identification and assessment, flexibility in schedule and budget adjustments, methods of monitoring and control, and practices for closure and documentation of managed risks. A comparative table summarising these aspects is presented below.

Table 1. Comparative table of risk management methods in case studies

Aspect	Project 1	Project 2	Project 3
Tools	MS Project, Power BI, Excel	Spring P6, Excel, Word	SWOT, Excel, MS Project
Risk Aproche	Weekly continuous identification, qualitative assessment	Bi-weekly identification, qualitative and quantitative evaluation	Identification in planning, qualitative assessment
Flexibility	Adjustments to schedule and budget	Adjustments to timeline and risk responses	Weekly adjustments and bi-monthly updates
Monitoring and Control	Monitoring with Power BI, internal audits	Continuous monitoring of impact on schedule	Weekly monitoring, bi-monthly review
Closure and Documentation	Lessons learned in Word and Excel	Lessons learned in Word and Excel	Lessons learned and risk review

As can be seen, all three case studies develop a systematic approach to risk identification and assessment, using tools such as probability and impact matrices. However, a key difference lies in the flexibility of schedule and budget adjustments, with some projects showing greater adaptability to unforeseen changes than others.

4.3. Propose a risk management model based on BIM and Monte Carlo to mitigate cost overruns.

• **Development of a simulation model based on BIM and Monte Carlo analysis.**

BIM Model for Preliminary Budgeting: Through Revit, a BIM model with a Level of Development (LOD) 300 was developed, suitable for the preliminary budgeting phase, which is shown in Figure 3. Besides, planning tables quantifying materials and unit costs were generated and are shown in Figure 4.

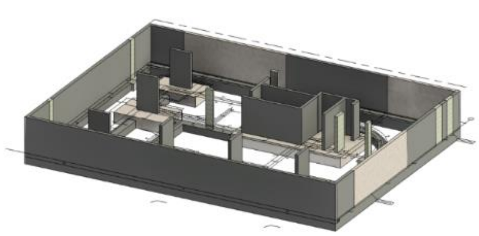


Fig. 3. BIM Modelling LOD 300 Foundation Stage

Structural foundation planning table - Concrete

Family and Type	Volume	Partial Price (PEN)	Total Price (PEN)
Isolated foundation: Z1- 2.45 x 4.00	7.84 m³	513.74	4027.72
Isolated foundation: Z1- 2.65 x 4.20	8.90 m³	513.74	4574.34
Isolated foundation: Z1- 2.65 x 4.20	8.90 m³	513.74	4574.34
Isolated foundation: Z1- 2.65 x 4.20	8.90 m³	513.74	4574.34
Isolated foundation: Z2- 2.85 x 4.40	11.29 m³	513.74	5798.07
Isolated foundation: Z2- 2.85 x 4.40	11.29 m³	513.74	5798.07
Isolated foundation: Z AXIS B	0.77 m³	513.74	394.55
Isolated foundation: Z AXIS B	0.77 m³	513.74	394.55
Isolated foundation: ZG	41.47 m³	513.74	21303.51
Isolated foundation: ZP	1.08 m³	513.74	553.81
Isolated foundation: ZP	1.08 m³	513.74	553.81
			52547.13

Fig. 4. Planning table of concrete quantity and price obtained by Revit

- **Monte Carlo simulation in @Risk:** In the @Risk software, PERT probability distributions were set up for each cost item and a Bernoulli distribution for the occurrence of risks. The simulation generated a probability distribution of total project costs, with multiple iterations (5,000-10,000) to reflect the impact of risks. The results were as follows:

Table 2. Table of monte carlo simulation results

Total Initial Cost	**S/ 423,232.91**
Total Cost Sampled	**S/ 427,939.89**
Likelihood of meeting the Total Initial Cost	7.60%
Total cost required for 95% confidence	S/ 484,702.00
Contingency required for 95% confidence	S/ 61,469.09

The Monte Carlo simulation allows the risks associated with the initial budget of a construction project to be assessed. According to the results, the total initial projected cost is S/ 423,232.91, while the average total cost obtained from the simulations is S/ 427,939.89, which reflects a slight increase due to the inclusion of risks. Furthermore, the probability of meeting the initial cost is only 7.60%, indicating a high risk of cost overruns. To achieve a 95% confidence level, it is estimated that the total cost should be S/ 484,702.00, which implies the need for a contingency of S/ 61,469.09.

- **Development of a method for mitigating cost overruns using BIM and Monte Carlo analysis.**

The proposed method for risk management in construction projects aims to implement a structured and effective approach throughout the entire project life cycle. This process spans from initial planning to closure, ensuring the identification, analysis, mitigation and monitoring of risks. Priority is given to the use of advanced tools such as BIM and Monte Carlo simulations to forecast financial and technical risks, enabling better resource management and budget optimisation. In addition, continuous communication and the integration of preventive and corrective strategies are promoted in order to minimise negative impacts on the project. All these aspects have been grouped together including the integration of BIM and Monte

Carlo tools as a proposed risk management method to mitigate cost overruns which is shown in a flow chart in the following.

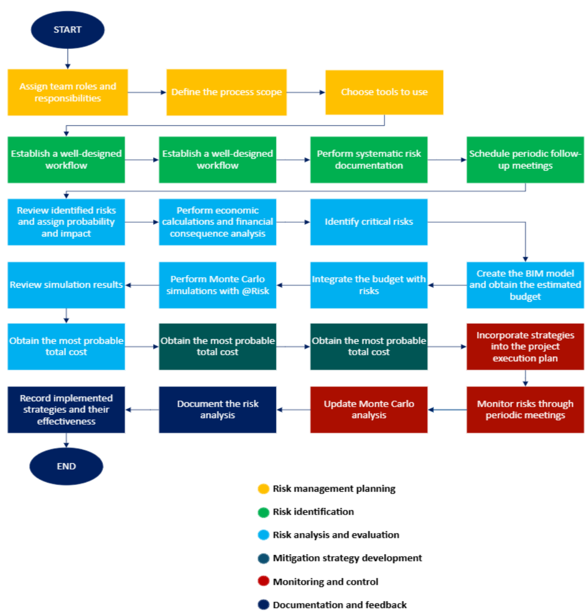


Fig. 5. Flowchart of the proposed risk management approach to mitigate cost overruns

➢ Risk Management Planning

At this stage there are interactions between the project manager, the resident engineer and the technical office engineer.

- The project manager leads the assignment of roles and responsibilities, defines the scope of the process, chooses the tools and establishes communication channels.
- The resident engineer assists in designing an efficient workflow and ensures that responsibilities are well distributed.
- The technical office engineer verifies that the selected tools are technically feasible and that the defined processes are integrated with the project design. These interactions ensure alignment of objectives and efficient planning of the entire process.

➢ **Risk Identification (before and during implementation)**

At this stage, all the roles involved participate: the project manager, resident engineer, technical office engineer, production engineer, quality engineer and safety engineer.

- During the identification meetings, each professional provides information from his or her speciality. For example, the safety engineer identifies occupational risks, the quality engineer evaluates risks associated with project standards, and the production engineer analyses risks in the execution of the work.
- The project manager oversees the meetings and ensures that critical risks are prioritised. These interactions allow for a comprehensive identification of risks from multiple perspectives.

➢ **Risk Analysis and Assessment**

At this stage, the key interactions are between the project manager, the resident engineer, the technical office engineer and the production engineer.

- The project manager leads the risk review and approves the priorities set.
- The technical office engineer performs technical calculations, runs Monte Carlo simulations and presents likely scenarios.
- The resident engineer and production engineer provide practical input from the field, validating simulation results and cost estimates. These interactions ensure that decisions are based on reliable data and operational experience.

➢ **Developing Mitigation Strategies**

The project manager, the resident engineer, the technical office engineer, the production engineer, and the quality and safety specialists collaborate at this stage.

- The project manager approves the proposed preventive and corrective strategies.
- The resident engineer oversees that the strategies are practical and applicable on site.
- The technical office engineer integrates strategies into designs and construction procedures.

Quality and safety engineers assess that strategies comply with established standards and safety regulations. These interactions ensure the implementation of viable, comprehensive and effective strategies.

➢ **Risk Monitoring and Control**

During this stage, the project manager, the resident engineer, the production engineer and the technical office engineer work together.

- The project manager leads regular meetings to monitor the implementation of the strategies and manage adjustments.
- The resident engineer monitors progress in the field and communicates any deviations or emerging risks.

- The technical office engineer updates Monte Carlo models and cost projections based on the latest data.

  These interactions ensure an effective and agile response to changes or newly identified risks.

- **Documentation and Feedback**

In this last stage, the project manager, the resident engineer, the technical office engineer and the quality and safety specialists interact.

- The project manager leads the collection of information on the effectiveness of the strategies implemented and documents lessons learned.
- The resident engineer provides practical information from the field, while the technical office engineer organises and records the results in the project systems.
- Quality and safety specialists verify the effectiveness of strategies from their respective areas and generate reports for feedback.

  These interactions ensure continuous improvement and knowledge transfer to future projects.

4.4. Demonstrate the advantages of the method

The proposed method, which integrates BIM and Monte Carlo analysis for cost and risk management in multi-family projects, showed several advantages compared to traditional methods used in the sector. Clear benefits in cost management, risk identification and decision making during the project were identified. The advantages identified are as follows:

1. **Increased accuracy in cost estimation**: The integration of detailed data and advanced simulations allows more accurate estimates to be generated, reducing common errors in financial planning.
2. **Simulation of risk scenarios**: The use of Monte Carlo analysis facilitates the assessment of multiple possible scenarios, helping to anticipate and prepare strategies in the face of potential risks.
3. **Proactive risk management**: Early identification and continuous monitoring of risks improves the ability to implement corrective measures before problems significantly impact the project.
4. **Optimisation of contingency margins**: Thanks to simulations, tighter contingency margins can be determined, optimising the use of financial resources without compromising project security.
5. **Continuous control and updating of costs**: BIM allows dynamic and up-to-date cost control to be maintained throughout the stages of the project, reflecting changes in real time.
6. **Better decision making**: Comprehensive visualisation and quantitative data generated by BIM and Monte Carlo provide teams with more robust information to make informed strategic decisions.

5. Analysis of results

One of the most relevant findings of the study was the identification of the main risks affecting project cost overruns. Common factors such as inaccuracies in cost estimation, problems in the initial design and conflicts with contractors were identified as the most frequent and have a high impact. In particular, inaccuracies in cost estimation were identified as the main cause of cost overruns, with an incidence of 50%, highlighting the need for more sophisticated methodologies to allow more accurate cost control from the early stages of the project. This finding highlights the importance of using tools such as BIM, which facilitates more detailed and accurate estimation from preliminary design, and Monte Carlo analysis, which allows modelling of uncertainty and risks associated with costs.

The proposed risk management model, based on the integration of BIM and Monte Carlo analysis, proved to be an effective tool for mitigating cost overruns. BIM allowed for a more accurate estimation of costs from design, and the Monte Carlo simulation provided a more realistic assessment of risks and their cost impacts. This approach allowed not only to improve the accuracy of the initial estimates, but also to optimise the allocation of resources and adjust contingencies dynamically as risks developed in the project.

On the other hand, the advantages of this integrated approach are clear. The use of BIM allowed for a more detailed representation of building elements and accurate quantification of materials, which facilitated the creation of a more reliable budget. Monte Carlo analysis, on the other hand, improved decision-making by providing a range of possible outcomes, allowing project managers to make informed decisions and adjust the budget and schedule according to identified risks.

6. Validation

Validation of the proposed risk management methodology was carried out through a survey of 30 industry specialists to assess its effectiveness, acceptability and feasibility. The method, which combines BIM methodology and Monte Carlo Analysis, was evaluated on four key aspects using a scale of 1 to 5, where 1 indicates total disagreement and 5 represents total agreement. These results provide insight into the overall acceptance of the method and highlight potential areas for improvement identified by the participants.

In terms of questions, the first question of the survey focused on the respondents' perception of the ability of the method to mitigate cost overruns in multi-family building projects due to risks. The second question assessed the effectiveness of the integration of BIM and Monte Carlo in mitigating cost overruns. The third question asked whether the method covers the necessary aspects for the feasibility of its application in real projects. The fourth question sought to assess the clarity of the steps to integrate BIM and Monte Carlo.

When the full results were reached, the positive responses (levels 4 and 5) of the respondents were grouped together to obtain a clearer analysis of the respondents' perceptions.

The results for the first question showed a majority acceptance of the method, with more than 80% of the specialists agreeing on its effectiveness in mitigating cost overruns and improving risk management. Likewise, the results for the second question about the integration of BIM and Monte Carlo analysis were perceived favourably, with 85% recognising its potential to improve cost overrun mitigation. For the third question, the feasibility of the application of the method and the integration in real projects is accepted by 82% of the respondents, showing that the method covers the necessary aspects for integrated risk management and its application in real projects. Finally, in fourth question, which assesses whether the steps to explain the integration of the tools are clear, 85% of the respondents approved

7. Conclusions

- The literature review and surveys conducted identified the most frequent and high impact risks in multi-family building projects, such as cost estimation, initial design problems and difficulties with contractors. These risks have a high frequency and a significant impact on the success of projects, which underlines the need for effective mitigation strategies.
- The comparative analysis of three multi-family projects highlighted significant variations in the use of tools, flexibility to change and monitoring practices in risk management. The analysis showed that while the case studies adopted structured approaches to identifying and assessing risks, the effectiveness of monitoring, control strategies and flexibility in managing schedules and budgets varied considerably, highlighting opportunities to improve the response to unforeseen risks.
- The developed model successfully integrated both tools to simulate risk scenarios, allowing an accurate assessment of potential cost overruns and facilitating data-driven decision making. The proposed method allows for anticipating

cost overruns and defining tight contingency margins, improving resource management and reducing uncertainties in construction projects.

- The implementation of the method showed clear benefits, such as increased accuracy in cost estimation, proactive risk management, optimisation of contingency margins and continuous cost control. This confirms its superiority over traditional methods in terms of efficiency and results.

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