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QUANTITY TAKE-OFF IN ROUGH CONSTRUCTION OF HIGH-RISE BUILDINGS BASED ON CAD AND BIM METHODOLOGIES: A CASE STUDY

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ABSTRACT

Building Information Modeling (BIM) prepares the quantity take-off (QTO) of the construction elements, helping in the management of the design and construction process and preparing the 3D visualization of the construction phases. BIM increases efficiency and gives users more control over construction-related tasks. This study identifies the New Cycle building as a Case Study, in which inconsistencies were detected in the QTO, compared to the real quantities of budgeted materials, so the interested parties decided to implement BIM in the use of QTO as a mechanism of control. The central question addressed was: If BIM had been implemented at the tender stage, could it have provided benefits to the project? To do this, various parameters were evaluated to conduct a comparative analysis between the results obtained through the use of the CAD and BIM methodology in the same project. Using the Analytical Hierarchy Process (AHP) method, it was possible to evaluate and compare the two alternatives, CAD and BIM, in order to determine which of them would have been more effective in satisfying the objectives set in the project. The results obtained offer a valuable and informed vision for making informed decisions for future construction projects, contributing to a change in perception about the adoption of new work methodologies.

KEYWORDS

Building Information Modeling; quantity take-off; work flow; collaboration.

INTRODUCTION

Lean Construction is the delivery process that uses Lean theories, principles, techniques and tools to maximize stakeholder value and minimize waste by emphasizing team collaboration on a project. The goal of Lean Construction is to drive productivity, profits and innovation in the industry, enabling the entire construction project lifecycle to benefit from the application of many Lean principles.

BIM (Building Information Modeling) is a well-known tool to improve the design and construction of buildings. It is based on the digitalization of all project information, which allows better control and monitoring of the project. BIM not only changes the technology used, but also the way of working. This is a cultural change that involves all the agents participating in the project, from architects and engineers to builders and owners. Although these approaches are different initiatives, there are synergies between Lean and BIM that are most effective when implemented together and not separately (Garcés & Peña, 2023; Michalski et al., 2022; Sacks

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et al., 2017). The precision of BIM and the Lean approach to eliminating errors minimize the costs associated with rework and modifications. The combination of Lean Construction and BIM in the early stages of the project allows you to optimize the design and construction processes, eliminate waste and generate a more efficient, profitable and sustainable project.

LITERATURE REVIEW

While BIM addresses the reliability of information in construction projects, Lean addresses the reliability of processes to reduce or eliminate waste (Fosse et al., 2017; Nguyen & Akhavian, 2019; Garcés & Peña, 2022). Regarding the use of building information models (BIM) in design and construction projects, which cover work processes and team organization, it is worth highlighting the pioneering work of the Center for Integrated Facilities Engineering (CIFE) of the University. from Stanford. This center developed a new concept called Virtual Design and Construction (VDC), which is based on the integration of new BIM technologies with Lean philosophy and practices (Kunz & Fischer, 2020). VDC tools can be very effective in achieving Lean Production Delivery System (LPDS) objectives (Aslam et al., 2021).

In this sense, BIM (Building Information Modeling), VDC (Virtual Design and Construction) and Lean Construction are three methodologies that overlap and complement each other to significantly improve the efficiency and success of the construction project (Fosse et al., 2017; Nguyen & Akhavian, 2019; Aslam et al., 2021). For example, 1) BIM provides the database and platform for the integration of VDC and Lean; 2) VDC uses the BIM model for simulation, planning and project management, and 3) Lean guides the implementation of VDC and BIM to eliminate waste and optimize the process. This overlap improves communication and collaboration between different disciplines, reduces errors and costs during design and construction, optimizes project planning and execution, improves project quality, safety and sustainability, and reduces delivery time and project costs.

That said, in the construction industry, effective cost and time management is crucial to achieving project success, which is why various investigations have addressed it through the BIM methodology and Lean Construction techniques and tools. Where, timely completion, cost control, and compliance with quality and performance requirements define achievement (Parsamehr et al., 2023). Improving work and production processes is essential for this success. Construction project stakeholders, including owners, architects and general contractors, are increasingly aware of ways to reduce time and costs, including cost estimating using BIM, as the architecture, engineering and Construction (AEC) adopts building information modeling (BIM) in its construction (Gholizadeh et al., 2018; Jin et al., 2017). Compared to conventional estimating methods, research studies have shown that using BIM for estimating reduces work time and errors and improves estimator performance (Kim et al., 2019; Peterson et al., 2011).

However, the use of BIM estimation comes with several challenges, including: (1) a lack of knowledge and understanding of BIM on the part of the estimator; (2) implementing data sharing between various applications such as estimating software and BIM creation tools; and (3) limitations in maintaining relationships between cost information and construction elements modeled in three-dimensional (3D) objects (Aibinu & Venkatesh, 2014; Kim et al., 2019).

BIM is characterized by being a methodology that optimizes performance and productivity in construction projects, achieving greater efficiency and collaboration in the processes. This methodology allows architects, engineers and builders to develop projects effectively throughout their life cycle, which, in turn due. An inconsistency in the quantity extracted from building components can make the quantities calculated difficult. This is because the quantities used to prepare a budget during the design phase serve as a basis for calculating the tender price, and evaluating the suitability of construction cost when deciding on a general contract, therefore, accurate measurements must be made to reduce the possibility of the total construction cost increasing or decreasing during construction (Ashworth & Perera, 2015; Hyari, 2016).

Due to the lack of investigations of real cases of quantity take-off (QTO) of high-rise buildings, this research compares the results of QTO based on traditional methodology, such as CAD, and on BIM methodology through a case study, which is a 16-story building plus two basements. The QTO of concrete, reinforcing steel bars, and formwork, prepared through CAD for the budget of the New Cycle project, is referred to as “QTO CAD”; and the QTO using the BIM methodology for this research is called “QTO BIM”.

Combining various studies and analyses, this research assessed whether Building Information Modeling (BIM) would present advantages or benefits to the Computer-Aided Design (CAD) in a specific case study. The aim was to identify the best approach for achieving accurate quantity take-off (QTO) results and minimizing material waste. To make this complex decision, the Analytical Hierarchy Process (AHP), a structured technique for evaluating multiple factors, was employed.

The AHP Method is a useful tool for making complex decisions with multiple factors to consider. It is based on decomposing the problem into a hierarchy of elements and then comparing them pairwise (one against one) to determine their relative importance (Darko et al., 2019). The AHP Method has the following steps: 1) Define the problem: What decision do you want to make?; 2) Decompose the problem: Identify the different factors that influence the decision; 3) Organize the factors in a hierarchy: Create a structure that groups the factors by levels of importance; 4) Compare the factors: Compare each pair of factors at each level of the hierarchy to determine which is more important; 5) Calculate priorities: Assign numerical values to comparisons to determine the relative importance of each factor; 6) Synthesize the results: Combine the priorities of the different factors to obtain a final decision. AHP is a powerful tool for making complex decisions with multiple factors to consider. It is simple to understand and use, and can help you make more informed and objective decisions.

CASE STUDY

The present research focuses on the comparative analysis of the uses of CAD and BIM in QTO of the core work of the New Cycle building, located in the city of Concepción, Chile. During the developing of this research, New Cycle has been in the construction and completion stages. This case study consists of a residential building for apartments. In addition, its design includes 16 floors, 2 basements and various spaces for uses and services (see Figure 1).

BIM Model of the New Cycle Building | Render of the New Cycle Building | Simulation of the construction process

Figure 1: BIM model and render of the case study building.

The Real Estate Company that manages New Cycle made a 3D model of the building, in the early stages of the project, which was more linked to the architecture, so it was used only as a rendering of the building. Given this, the project's Construction Company decided to remake the model, integrating all the specialties, where the concrete modeling was considered.

For the structural part, a new 3D model was developed, given that its design characteristics required different skills that the construction company´s modeling area did not have. They were developed in collaboration with modeling contractor companies specializing in the design and installation of steel bars. Finally thanks a "plugin" (PROISAC-encofrados) allowed obtaining the m^2 of formwork based on the concrete model BIM. The objectives set with this structural model were: 1) optimize the purchasing process, 2) identify incompatibilities of the reinforcing steel bars project, and 3) increase efficiency in execution, since, if the bars are designed to be easily sized and installed, the purchasing process would be faster, thus avoiding delays in the execution of the heavy work process due to the high latency in the response of the estimator, and on the other hand, the amount of steel on the ground would be reduced, avoiding the performance of repetitive work, thus increasing the work efficiency of workers.

With this, at New Cycle BIM was implemented with 2 models: one to manage the control and execution of the installation of steel bars and another model that integrates and coordinates the specialties, in order to keep track of both modifications and real-time progress of the project.

PROBLEMATIC

Due to differences in the budgeted QTO of materials versus the actual ones used, the need arises to create a quantity control mechanism, including the modifications that may bring about changes in requirements and design. Given this, the use of CAD methodologies in the case study for the QTO is evaluated to contrast it with the QTO obtained through BIM models (QTO CAD vs QTO BIM), in order to study the impact on the project if BIM had been implemented at the beginning, over the traditional applied work methodology, this is CAD. To study the impact on the difference in quantities of materials, the bulk construction stage is analyzed exclusively, The integration of BIM in the construction industry presents a comprehensive solution to enhance material usage efficiency, notably curbing waste across projects. By enabling precise and detailed planning, BIM facilitates surplus minimization and efficient inventory management, thereby fostering a cleaner and more sustainable work environment.This approach closely aligns with Waste Management principles in construction, where waste reduction and value maximization stand as pivotal objectives in enhancing sectoral efficiency and sustainability, resonating with Lean Construction principles, which prioritize waste elimination and process optimization towards achieving more efficient and profitable outcomes.

The main items within the gross construction work are concrete (m^3), reinforcing steel bars (tons) and formwork (m^2) (Choi et al., 2015; Garcés & Molina, 2023; Liu et al., 2022; Olsen & Taylor, 2017; Whang & Park, 2016), and correspond to the instances that require more time and costs, therefore, the QTOs carried out and studied correspond to these three items.

SOFTWARE USED

The QTOs were made with CAD files (Autodesk AutoCAD) with which the building project was budgeted. The information collected from plans was transferred to Excel spreadsheets for data processing. The entire model was made in Revit, only the ironing machine model was made by TSC Company in Tekla Structures and then transferred to the Trimble viewer through an IFC format. Finally, for the application of the AHP method as a decision maker to determine the best alternative for QTO, the Total Decision software was used, a program specialized in the matrix development of this method.

Certain ranges of percentage differences based on current industry references were established to define how acceptable the results obtained are when comparing the QTO in CAD and BIM of the New Cycle building with the QTO carried out in this research, these are: (1) <2% acceptable; (2); 2-5% moderately acceptable; and (3) >5% not acceptable.

ANALYSIS OF RESULTS

To carry out the QTO comparison, three parameters were considered: (1) the QTO of Concrete, reinforcing steel bars and formwork, made using CAD with which the New Cycle project budget was developed (hereinafter "CAD NC"), delivered at the bidding stage of the construction project; (2) and the QTO of Concrete, steel bars and formwork, using New Cycle BIM models (hereinafter "BIM Research"). Thus, with these QTO parameters, through the comparison "CAD NC vs BIM Research" you can know the differences between what was budgeted and what was required in the execution of the project. It should be noted that these are geometric calculations without considering the waste of execution. See Figure 2.

QTO comparisons are presented using results by level, from the foundation slab, basement -2 and -1 and floors 1 to 16.

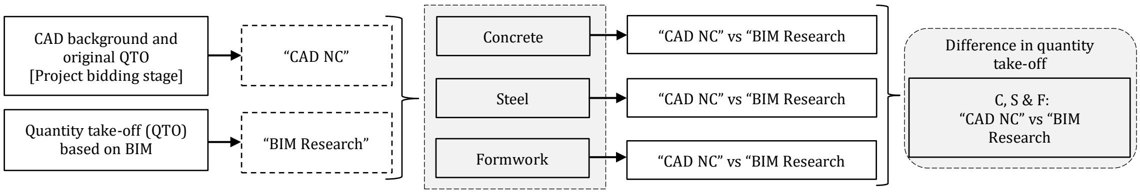

Figure 2: Quantity take-off of the New Cycle (NC) building.

CONCRETE: "CAD NC" VS "BIM RESEARCH"

Table 1 shows that "CAD NC" calculated 5856.00 m³ of concrete, while "BIM Research" recorded 5719.87 m³. The totals differ by 136.13 m³, representing a 2.32% percentage difference. The high level of detail in the "BIM Research" models provides a more precise and realistic estimate of the volume of concrete required for the New Cycle project. In the foundation slab and basement -2 and -1 the differences are negative, indicating that "CAD NC" quantities of concrete were underestimated. Under the acceptability criteria, the foundation slab presents an unacceptable difference, while both basement have moderately acceptable differences between CAD and BIM applications. On the other hand, for Floors 1 to 16, the differences are considered unacceptable, which implies that "CAD NC" calculated a volume of concrete above the real needs of the project.

"CAD NC" carried out the calculation by elevations, considering the total lengths of each level. In addition, "BIM Research" takes into account empty spaces where concrete is not required, such as shafts, which contributes to a calculation adjusted to reality.

It is important to mention that the difference that occurs on the 16th Floor is due to a redesign on said floor, reducing its area, and therefore, its amount of concrete. This modification was not considered by "CAD NC".

Table 1: Concrete CAD and BIM Results

	CAD NC	BIM Research	Difference	% Difference
TOTAL	5856.00 m³	5719.87 m³	136.13 m³	2.32%
Foundation slab	1394.84 m³	1665.94 m³	-271.10 m³	-19.44%
Basement -2	445.81 m³	455.81 m³	-10.00 m³	-2.24%
Basement -1	470.40 m³	487.53 m³	-17.13 m³	-3.64%
1st Floor	244.05 m³	219.12 m³	24.93 m³	10.21%
2nd Floor	227.90 m³	186.99 m³	40.91 m³	17.95%
3rd Floor	234.85 m³	214.91 m³	19.94 m³	8.49%
4th Floor	234.85 m³	214.89 m³	19.96 m³	8.50%
5th Floor	234.85 m³	215.40 m³	19.45 m³	8.28%
6th Floor	234.85 m³	215.63 m³	19.22 m³	8.19%
7th Floor	234.85 m³	215.69 m³	19.16 m³	8.16%
8th Floor	234.85 m³	215.79 m³	19.06 m³	8.12%
9th Floor	234.85 m³	214.78 m³	20.07 m³	8.55%
10th Floor	234.85 m³	214.50 m³	20.35 m³	8.67%
11th Floor	234.85 m³	214.68 m³	20.17 m³	8.59%
12th Floor	234.85 m³	210.51 m³	24.34 m³	10.37%
13th Floor	234.85 m³	215.25 m³	19.60 m³	8.35%
14th Floor	234.85 m³	187.35 m³	47.50 m³	20.23%
15th Floor	211.24 m³	131.97 m³	79.27 m³	37.52%
16th Floor	43.53 m³	23.13 m³	20.40 m³	46.87%

STEEL BARS: “CAD NC” VS “BIM RESEARCH”

The observed differences caused problems in terms of project processes and costs. There is a difference of -61.93 tons of iron, which represents a discrepancy of 10.02% compared to the amount budgeted by “CAD NC” (see Table 2). Both positive and negative differences are identified in Floors 3 to 14, but all of them are within the acceptable and moderately acceptable range. However, the foundation slab, basement -2 and -1, and Floors 1, 2, 15 and 16 present differences that are not acceptable according to the established criteria. It is important to highlight that the greatest differences are evident in basements -2 and -1, where “CAD NC” considerably underestimated the amount of steel bars required compared to “BIM RESEARCH”

“BIM Research” considers all the elements of the steel bars, even those that do not have a structural function, but are necessary from a construction point of view, such as extra locks, splices and hooks, to support slabs, and master bars, among others. These additional elements are not detailed in the plans, but are required during the installation of the steel bars. This difference in the consideration of non-structural elements explains why “BIM Research” shows superior steel QTO results than “CAD NC”.

Table 2: CAD and BIM results of reinforcing steel bars

	CAD NC	BIM Research	Difference	% Difference
TOTAL	617.88 Ton	679.81 Ton	-61.93 Ton	-10.02%
Foundation slab	64.14 Ton	70.82 Ton	-6.68 Ton	-10.41%
Basement -2	44.05 Ton	81.45 Ton	-37.40 Ton	-84.89%
Basement -1	43.19 Ton	67.45 Ton	-24.26 Ton	-56.17%
1st Floor	39.85 Ton	52.06 Ton	-12.21 Ton	-30.65%
2nd Floor	44.68 Ton	40.76 Ton	3.92 Ton	8.78%
3rd Floor	36.09 Ton	34.53 Ton	1.56 Ton	4.33%
4th Floor	32.42 Ton	33.45 Ton	-1.03 Ton	-3.17%
5th Floor	30.85 Ton	30.14 Ton	0.71 Ton	2.31%
6th Floor	29.58 Ton	30.31 Ton	-0.73 Ton	-2.47%
7th Floor	28.33 Ton	27.86 Ton	0.47 Ton	1.65%
8th Floor	27.96 Ton	28.53 Ton	-0.57 Ton	-2.03%
9th Floor	26.68 Ton	26.66 Ton	0.02 Ton	0.07%
10th Floor	26.43 Ton	27.15 Ton	-0.72 Ton	-2.71%
11th Floor	26.02 Ton	25.77 Ton	0.25 Ton	0.97%
12th Floor	26.00 Ton	26.66 Ton	-0.66 Ton	-2.56%
13th Floor	25.37 Ton	25.32 Ton	0.05 Ton	0.19%
14th Floor	24.56 Ton	25.62 Ton	-1.06 Ton	-4.31%
15th Floor	24.38 Ton	20.90 Ton	3.48 Ton	14.28%
16th Floor	17.31 Ton	4.39 Ton	12.92 Ton	74.64%

It is important to note that there was modification to design of the 16th floor that decreased the buildable area and was not considered by “CAD NC”, which shows that the amount of steel was greater than that actually required for that level.

The “BIM Research” study shows the superior precision of BIM for calculating the QTO of steel. Including non-structural elements in BIM is crucial for accurate estimating, resulting in better project management and transparency in real cost. The literature on BIM and construction project management supports these findings. Furthermore, the inclusion of non-structural elements in BIM is crucial for accurate estimation of steel QTO, and the lack of these elements in CAD NC underestimates the QTO, which can lead to problems during construction. Therefore, BIM offers greater precision in material estimation, which makes real cost transparent and optimizes project management.

FORMWORK: “CAD NC” VS “BIM NC”

Between the results of “CAD NC” and “BIM Research” there is a difference of 229.36 m² of formwork, which translates into a differential of 0.81% between what was budgeted and what was used (see Table 3). The total difference turns out to be very slight, with various differences, positive and negative, existing in the calculations for each level of the building. in foundation slab, basement -2 and -1, floors 1, 2 and 16 the differences are negative, that is, what was budgeted was less than what was required. The “not acceptable” results are offset by the results that are “moderately acceptable”, finally having a total difference categorized as “acceptable” between the CAD and BIM methodologies in formwork QTO.

Table 3: CAD and BIM results of formwork

	CAD NC	**BIM Research**	**Difference**	**% Difference**
TOTAL	28421.00 m²	28191.64 m²	229.36 m²	0.81%
Foundation slab	112.80 m²	126.47 m²	-13.67 m²	-12.12%
Basement -2	2154.24 m²	2482.91 m²	-328.67 m²	-15.26%
Basement -1	2294.80 m²	2583.88 m²	-289.08 m²	-12.60%
1st Floor	1490.60 m²	1577.68 m²	-87.08 m²	-5.84%
2nd Floor	1551.16 m²	1813.38 m²	-262.22 m²	-16.90%
3rd Floor	1582.69 m²	1502.75 m²	79.94 m²	5.05%
4th Floor	1582.69 m²	1508.76 m²	73.93 m²	4.67%
5th Floor	1582.69 m²	1507.23 m²	75.46 m²	4.77%
6th Floor	1582.69 m²	1503.03 m²	79.65 m²	5.03%
7th Floor	1582.69 m²	1505.59 m²	77.10 m²	4.87%
8th Floor	1582.69 m²	1506.66 m²	76.03 m²	4.80%
9th Floor	1582.69 m²	1506.18 m²	76.51 m²	4.83%
10th Floor	1582.69 m²	1499.78 m²	82.91 m²	5.24%
11th Floor	1582.69 m²	1506.78 m²	75.91 m²	4.80%
12th Floor	1582.69 m²	1507.38 m²	75.31 m²	4.76%
13th Floor	1582.69 m²	1472.15 m²	110.54 m²	6.98%
14th Floor	1582.69 m²	1507.26 m²	75.43 m²	4.77%
15th Floor	1462.26 m²	1204.45 m²	257.81 m²	17.63%
16th Floor	362.90 m²	369.34 m²	-6.44 m²	-1.78%

The difference with “CAD NC” vs “BIM Research” comparison is minimal: 0.81% (229.36 m²). This reinforces what was previously stated, that the formwork QTOs do not require a major analysis for the calculation of areas.

It should be noted that in order to obtain the quantities in m2 of the formwork, it is necessary to use a “plugin” given that the formwork is a temporary element that cannot be obtained directly from the BIM models.

AHP METHOD

Analytic Hierarchy Process (AHP) is a decision-making method in which alternatives are evaluated using a mathematical model, based on a series of criteria, to define which best meets the objective of a process (Darko et al., 2019). In this research, AHP is applied to define which alternative, CAD or BIM, best satisfies the requirements to develop QTO in the bidding stage.

To develop the AHP, the objective must be defined (“Define whether the CAD or BIM methodology is the best alternative to perform QTO and budget calculations in the bidding stage of a construction project”), and the criteria and alternatives (CAD and BIM) to make the best decision. The criteria were established based on input from experts consulted during the assessment phase of the Analytical Hierarchy Process (AHP). Six criteria are presented in Table 5 along with their corresponding sub-criteria. The first 4 criteria consider technical aspects that have direct implications in the use of CAD and BIM methodologies. Criteria 5 and 6 respond to qualitative aspects, which consider perceptions of barriers to overcome for the adoption and use of software related to work methodologies.

Due to the complexity of decision-making in construction projects, the AHP methodology emerges as a robust approach (Darko et al., 2019). It offers a systematic framework for evaluating and comparing multiple criteria, facilitating an informed selection between alternative methodologies such as CAD and BIM. The flexibility and adaptability of AHP allow for customization to address the specific needs of the research, ensuring a comprehensive evaluation that encompasses both technical and qualitative aspects (de Paris et al., 2022). Furthermore, in comparison to other decision-making methods like Cost-Benefit Analysis (CBA), AHP excels in its ability to consider a broader range of factors beyond purely monetary considerations (Arroyo et al., 2020; Natarajan et al., 2022), thus providing a more holistic and nuanced approach to decision-making in construction projects (Razi et al., 2019).

Table 5: AHP criteria and sub-criteria

N°	Criteria	Sub-criteria
1	Precision in quantity take-off	• Ability to identify elements in plans/models • Accuracy in the quantity of the elements identified
2	Efficiency in the quantity take-off process	• Speed of the QTO process • Degree of automation of the QTO process
3	Compatibility with other systems	• Ability to import and export data to other systems • Interoperability with other systems
4	Resource availability	• Availability of personnel trained in the use of the software • Availability of technical support and updates
5	Investment cost	• The initial cost of licenses • Cost of maintenance and updates
6	Easy to use	• Level of technical knowledge required to use software • The friendliness of the software interface

The first step to develop the AHP method in Total Decision is to enter the already established objective, criteria and alternatives. The criteria are then compared to each other, one by one, using ratings that indicate their degree of importance. With this process, the weights of each criterion are obtained in order to define the hierarchy between them, knowing which criteria are the most relevant within the analysis. The evaluations to compare criteria and alternatives based on the objective obey scores from 1 to 9 as presented in Table 6.

Table 6: AHP rating scale

Equal Importance	Moderate importance	Great importance	Very great importance	Extreme importance
1	3	5	7	9

The ratings entered into the software are based on information collected from interviews with experts. From this, each criterion was scored, understanding the degree of importance that each one has when carrying out the QTO, both by QTO CAD and QTO BIM. In this stage, the hierarchy of criteria is established, obtaining that the “Investment cost”" criterion is the one with the greatest weight, followed by the “Precision in QTO” criterion as the second most relevant. This indicates that the “Investment cost”, although not a technical aspect, is the most important criterion when making decisions about which work methodology to adopt to carry out QTO. Furthermore, the two main criteria are followed in the ranking by: “Efficiency in the QTO process”, “Compatibility with other systems”, “Resource availability” and, finally, “Easy to use”.

The next step is to evaluate each criterion concerning each of the alternatives. The same assessment scale used previously is used to rate the performance of each alternative based on the objective, as shown in Figure 3.

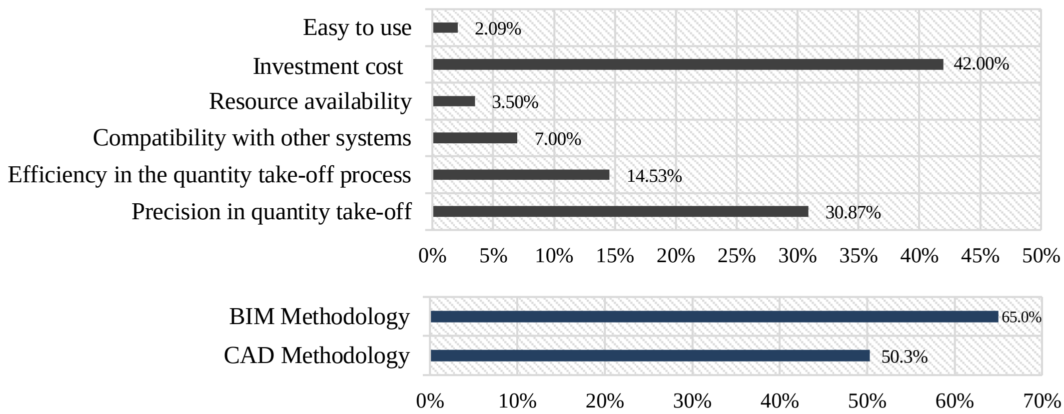

Figure 3: AHP structure of hierarchies.

These evaluations provide a measure of the performance of each alternative in relation to the objective. The evaluations are developed by matrixly ordering the results for each comparative instance. From each matrix, the eigenvectors are obtained that indicate the relative weights of each comparative pair. By obtaining all the eigenvectors, a global decision matrix is constructed with which, finally, the alternative with the greatest weight for decision-making can be obtained. This entire mathematical process was carried out using the Total Decision software.

Finally, with the AHP Method, through the calculation software, it is concluded that the best alternative to perform QTO and budget calculation in the bidding stage of a project is the BIM methodology over CAD.

Given that the “investment cost” criterion has high relevance in the study, considering that the costs associated with BIM are higher compared to CAD, the gap between alternatives may not turn out to be completely representative. That is why by carrying out the same study without considering the “investment cost” criterion, the decision-making is decisively more conclusive, defining BIM as the alternative with almost ideal performance to satisfy the objective, as shown in Figure 4.

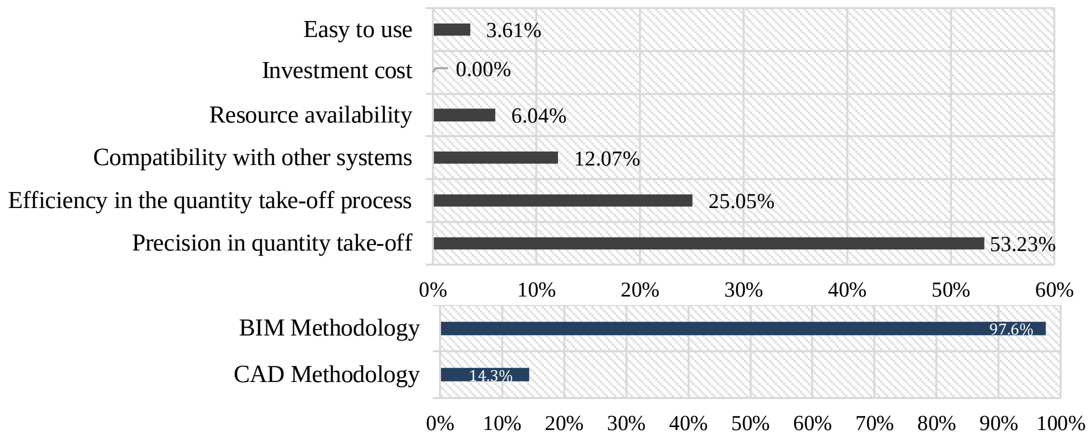

Figure 4: AHP sensitivity analysis - Simulation of results without Cost criteria.

This supports that the "investment cost" variable has a fundamental role in quantifying the best decision. However, in both cases, the BIM alternative presents the best performance, based on the criteria and its hierarchical analysis, to satisfy the objective of defining CAD or BIM as the best alternative to carry out QTO and budget in the bidding stage of a project.

QTO with CAD, unlike BIM, is based on individual 2D or 3D drawings, requiring manual calculation or using additional tools. This leads to errors due to the lack of integration between elements, making it difficult to update the calculation in the event of changes in the design. Instead, BIM creates an intelligent 3D digital model, allowing an automatic and precise calculation of materials from the model, minimizing errors and enabling rapid updating in the event of changes. This efficiency is applied to the calculation of concrete, reinforcement and formwork, optimizing the use of resources and collaboration between teams.

It is important to consider that the AHP method provides precise results after a mathematical development that integrates and weights various variables, delivering solid outcomes. By way of analysis, it is also important to understand that the use of AHP in decision-making can be affected by biases and limitations that must be addressed to ensure reliable results (Darko et al., 2019; Munier, N., & Hontoria, E. (2021). The judgments of experts, crucial in AHP analysis, may be influenced by personal preferences, limited knowledge, or external influences, which could bias evaluations (Liu et al., 2020). Additionally, the quality and availability of information for experts may vary, requiring measures to ensure equitable and comprehensive access to relevant information. The rating scales used in AHP analysis may be subjective and require validation to ensure accuracy (Darko et al., 2019). Faced with all this, it is necessary to carry out iterative processes and sensitivity analyses to evaluate the effectiveness of these scales and their impact on analysis results.

CONCLUSIONS AND RECOMMENDATIONS

The comparative analysis between the QTOs carried out with "CAD NC" and "BIM Research" has revealed important information regarding the precision and accuracy of the results. In the case of concrete, it is observed that "BIM Research" provides a real and precise quantity, avoiding overestimation of quantities, while "CAD NC" shows a tendency to overestimate volumes. This demonstrates the advantages of BIM in terms of obtaining accurate information and avoiding deviations in project processes and costs, and it could make projects more competitive by using them in earlier stages. Similarly, when comparing the QTO of steel bars, it is again evident that "BIM Research" offers a more detailed and complete analysis for the required elements, considering even those that do not have structural purposes but are necessary for construction. On the other hand, "CAD NC" presented discrepancies and errors in the study of plans, which generated imbalances in the processes and associated costs. It is important to highlight that the errors detected in the QTO are related to CAD, which supports the need to adopt more advanced methodologies such as BIM to avoid carryover of errors and detect incompatibilities early; This generates claims for defects in the design, which then end up being awarded to the client or assumed as a loss. In the case of the formwork, the results were quite similar in the totals, however, this required the help of a plug-in to have the calculations in BIM per floor, where the differences are within the moderately acceptable margins. described as criteria.

The study, using the AHP method, found that BIM (65%) outperforms CAD (50.3%) for performing QTO at the bidding stage. This is based on six criteria: accuracy, speed, ease of use, flexibility, collaboration and integration. The percentages are not absolute, but rather represent the relative performance of the alternatives. The AHP performs an independent analysis between alternatives.

While BIM is the best option, cost is a major barrier to its adoption. The implementation risk must be considered against the benefits of structuring, parameterization and process optimization that BIM offers. For construction professionals it is recommended: 1) Consider BIM as the best option for QTO in the bidding stage; 2) evaluate the cost of BIM implementation compared to the long-term benefits; and 3) seek strategies to mitigate the risk of BIM implementation. For researchers in this field, it is recommended: 1) Develop studies that demonstrate the value of BIM in terms of ROI (Return on Investment); 2) investigate strategies to reduce the cost of BIM implementation; 3) study the risk perception of BIM in the construction industry.

BIM adoption faces obstacles such as the need for training, investment in hardware and software, and adaptation to new work processes (Olanrewaju et al., 2022; Sriyolja et al., 2021). However, it is crucial to demystify the idea that BIM alone improves a project. While BIM offers great benefits, efficient processes are required to make the most of them. Resistance to change and lack of technological updating are also barriers that must be overcome (Shin & Kim, 2021). It is necessary to change the perception of BIM as something expensive and risky, and see it as an investment in improving the efficiency and quality of construction projects.

To overcome the challenges of BIM implementation, it is crucial to integrate the Lean Construction philosophy. Lean focuses on waste elimination and continuous improvement, which improves the efficiency of the BIM process and optimizes project performance. The integration of Lean and BIM offers benefits such as: 1) Reduction of costs and time, eliminating unnecessary activities and optimizing planning; 2) improved quality, minimization of errors and greater precision in construction; 3) greater collaboration among stakeholders, and 4) more effective decision making, based on accurate and up-to-date information and more effective decision making. Therefore, by integrating Lean into BIM from the early stages of the project, you boost competitiveness and ensure greater success in BIM implementation, optimizing overall project performance and minimizing waste.

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